DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Maryland 20084

OPERATION AND HYDRODYNAMIC EVALUATIONS OF A CONTROLLED-DEPTH TOWED DEPRESSOR DESIGNED TO HOUSE A CONDUCTIVITY, TEMPERATURE, DEPTH (CTD) INSTRUMENT SYSTEM

by

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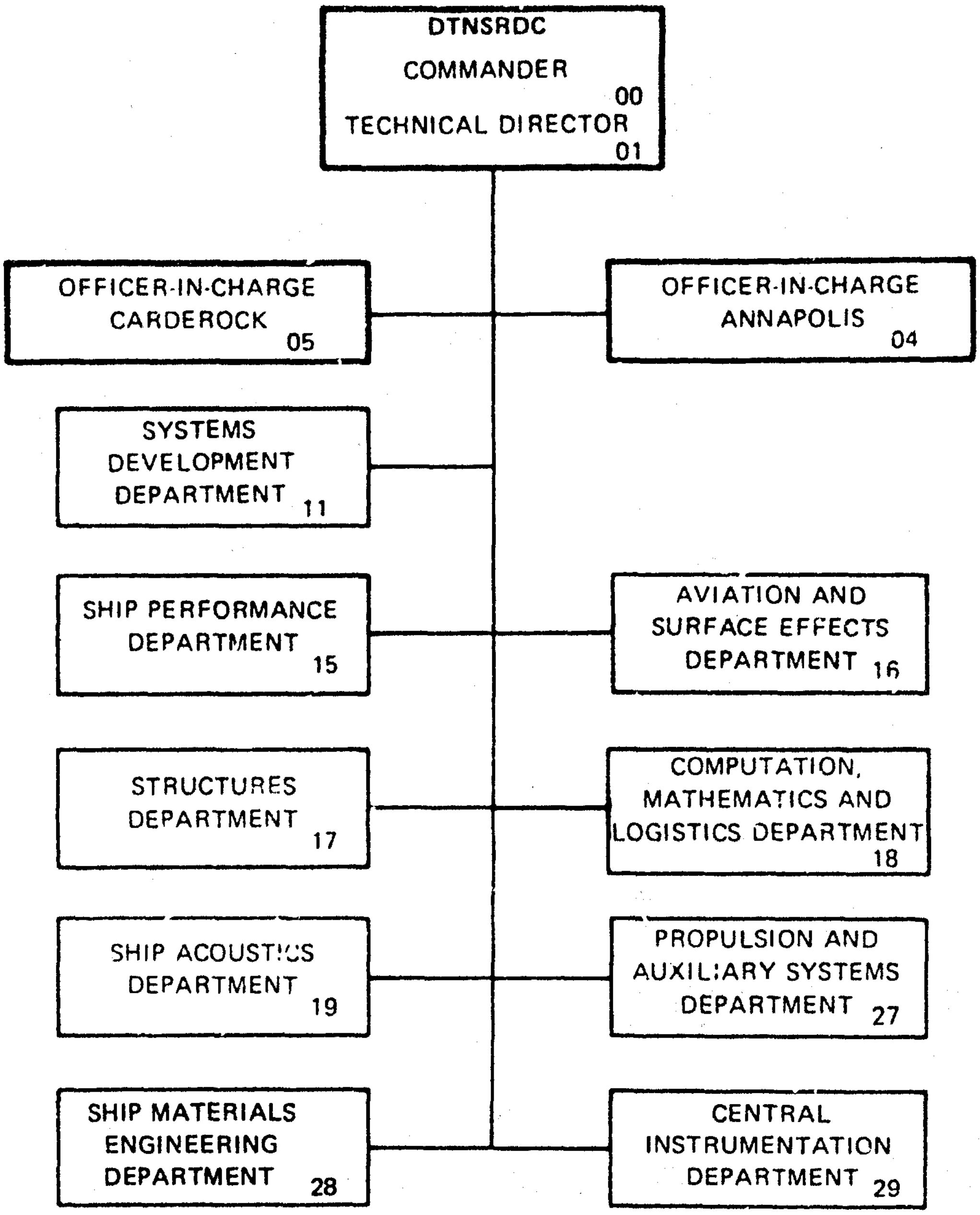

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A controlled-depth cable-towed depressor designed to house a conductivity, temperature, depth (CTD) instrument system is described. Design considerations are discussed, and the results of basin and preliminary at-sea evaluations conducted to ensure hydrodynamic performance are presented. The evaluations indicate that the basic design objectives were satisfied. Detailed hydrodynamic performance predictions as well as operation and maintenance guidelines are included in Appendices.

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NOTATION

A_o	Static depth variation corresponding to control flap deflection
A_1	Dynamic depth variation corresponding to control flap deflection
C_R	Cable normal drag coefficient
C_T	Depressor coefficient of tension
D	Depressor Drag
d	Cable diameter
f	Cable tangential drag factor
i_t	Tail incidence angle
K	Depth attenuation factor ($K \equiv A_1/A_o$)
L	Depressor lift
Re	Reynolds number
S	Wing projected area
T_o	Towcable tension produced by the depressor
V	Towing speed
δ	Control flap deflection
ρ	Water density
ϕ	Towcable angle

ABSTRACT

A controlled-depth cable-towed depressor designed to house a conductivity, temperature, depth (CTD) instrument system is described. Design considerations are discussed, and the results of basin and preliminary at-sea evaluations conducted to ensure hydrodynamic performance are presented. The evaluations indicate that the basic design objectives were satisfied. Detailed hydrodynamic performance predictions as well as operation and maintenance guidelines are included in Appendices.

ADMINISTRATIVE INFORMATION

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INTRODUCTION

The David W. Taylor Naval Ship Research and Development Center (DTNSRDC) was requested by the Naval Oceanographic Office (NAVOCEANO) to provide a controlled-depth towed depressor to house a conductivity, temperture, and depth (CTD) instrument system. In addition to sensors located at the depressor, provision for two sets of remote sensors to be located on the towcable were requested.

This report discusses design considerations and calculations to establish towing configurations and depressor wing forces; describes the resulting hardware and control electronics; and summarizes the results of basin and preliminary at-sea experiments conducted to examine towing performance of the depressor. Predicted performance curves as well as information concerning operation and maintenance of the equipment also are given.

DESIGN CONSIDERATIONS

The depressor is required to maintain selected depths to 200 m at speeds up to 10 knots. During steady towing, depth excursions no greater than ± 150 mm are desired, although excursions up to ± 300 mm are acceptable. Cyclic depth control of the depressor at frequencies from near zero to 0.2 Hz is required. Cycle amplitudes up to 7.6 m are desired at frequencies below 0.01 Hz; at frequencies above 0.01 Hz, cycle amplitudes up to 600 mm are desired.

Instrument space for the control electronics should be located in an area separated from the CTD electronics to avoid interference. An internal space 152 mm

in diameter and approximately 540 mm long is required for the CTD electronics. A single COAX conductor or an equivalent set of conductors is required in the tow-cable to transmit power and receive signals for the CTD; depth control functions should be provided by separate conductors.

The two remote sensor units will be positioned at various locations along the towcable. Maximum vertical separations from the depressor of 20 m and 10 m are required. Ideally, the vertical separations, relative to the depressor, should remain constant during cyclic depth control. The remote sensor units should be easily removable from the towcable to facilitate handling and repositioning.

PRELIMINARY DESIGN CALCULATIONS

A sketch of the general towing configuration is shown in Figure 1. An open loop configuration for the cables leading from the depressor to the remote sensors was selected as the only practical means of allowing variable positioning of the remote sensors. The remote sensor cable loops, however, will add substantial drag to the system. This extra drag will increase the variations in the remote sensor vertical separation during cyclic depth control; it also will increase the local stresses in the towcable at the attachment points as well as cause an increase in the overall towing tension.

Preliminary calculations were preformed to establish the length and tension of the remote sensor cables, the maximum length and tension of the towcable, and the maximum depressor force. Details of the calculations are presented below. A more complete set of performance predictions based on the selected towing equipment is presented in Appendix A.

REMOTE SENSOR CABLES

Calculations[1*] were performed to determine the remote sensor cable length for minimum cable tension. A cable diameter of 13 mm was assumed. This diameter should provide adequate area for both electrical conductors and a suitable strength member. Also, the cable was assumed to be faired over its entire length with ribbon fairing to prevent excessive strumming. Normal and tangential hydrodynamic loading functions determined from basin experiments,[2] with the tangential function multiplied

*A complete listing of references is given on page 79.

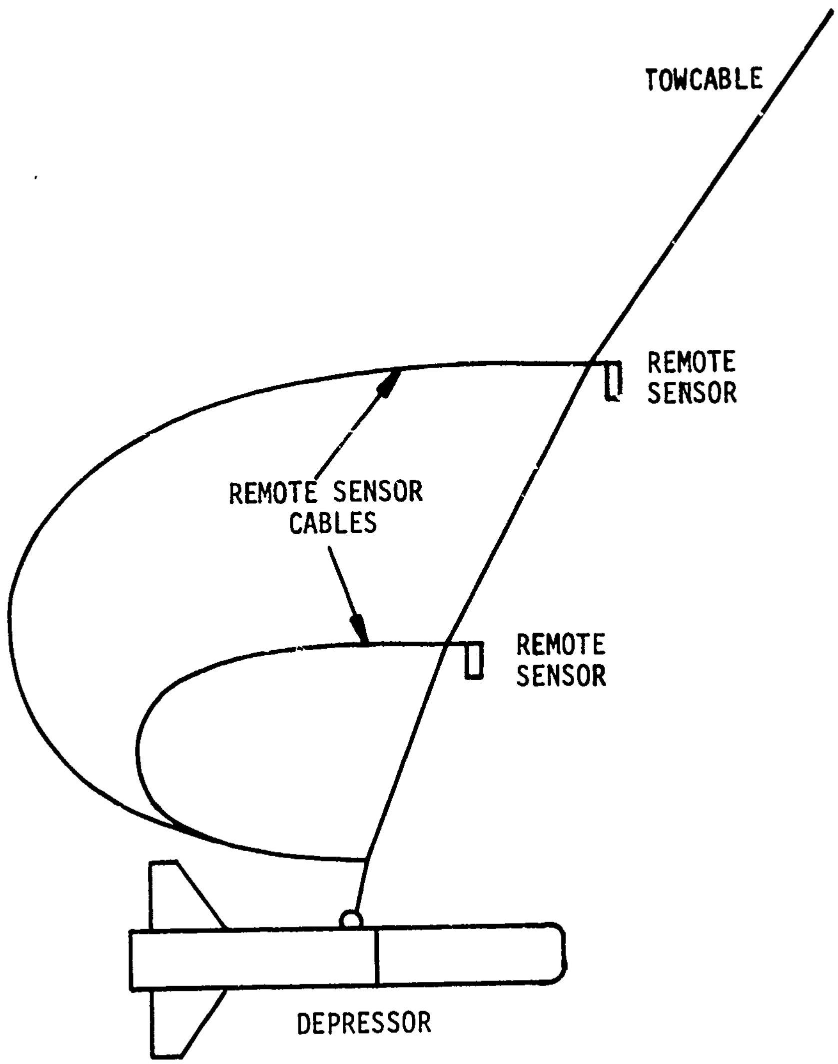


Figure 1 - Schematic of Conductivity, Temperature, and Depth Towing Configuration

by a factor of 0.55 to reflect DTNSRDC at-sea data, were used to calculate the cable configurations. The normal drag coefficient, C_R, based on cable diameter, also determined from at-sea data, was assumed to be

$$C_R = 5.23 - 0.85 \log_{10}Re \text{ (Ribbon Faired Cable)} \tag{1}$$

where Re is the Reynolds number based on diameter.

Predicted tension in the remote sensor cable as a function of cable length is shown in Figure 2. The results indicate that the length should be approximately twice that of the vertical separation of the ends for minimum tension.

TOWCABLE AND DEPRESSOR

A readily available, stock cable manufactured by Rochester Corporation was selected as a suitable towcable. This cable is double-armor construction utilizing galvanized improved plow steel as the strength member; it has nine electrical conductors in the core; the overall diameter is 0.343 in. (8.71 mm); and the rated breaking strength is 42.3 kN. For purposes of calculation, the towcable was assumed to be ribbon-faired for a length of 120 m starting from the depressor to gain the maximum depth advantage provided by the reduced normal drag of fairing. The remainder of the cable was left bare to prevent excessive tension buildup along the cable. Pode[3] loading was used for the normal and tangential components of drag for bare cable. The normal drag coefficient C_R based on cable diameter and the tangential drag factor f were assumed to be

$$\left.\begin{aligned} C_R &= 1.727 + \frac{6433}{Re} \\ f &= 0.0062 + \frac{53.45}{Re} \end{aligned}\right\} \text{(Bare Cable)} \tag{2}$$

The above equations were determine from DTNSRDC at-sea data.

The calculated towcable length and towing tension required to achieve a depth of 200 m at a speed of 10 knots are shown in Figure 3 as functions of tension produced by the depressor. The resulting towcable breaking strength factor of safety

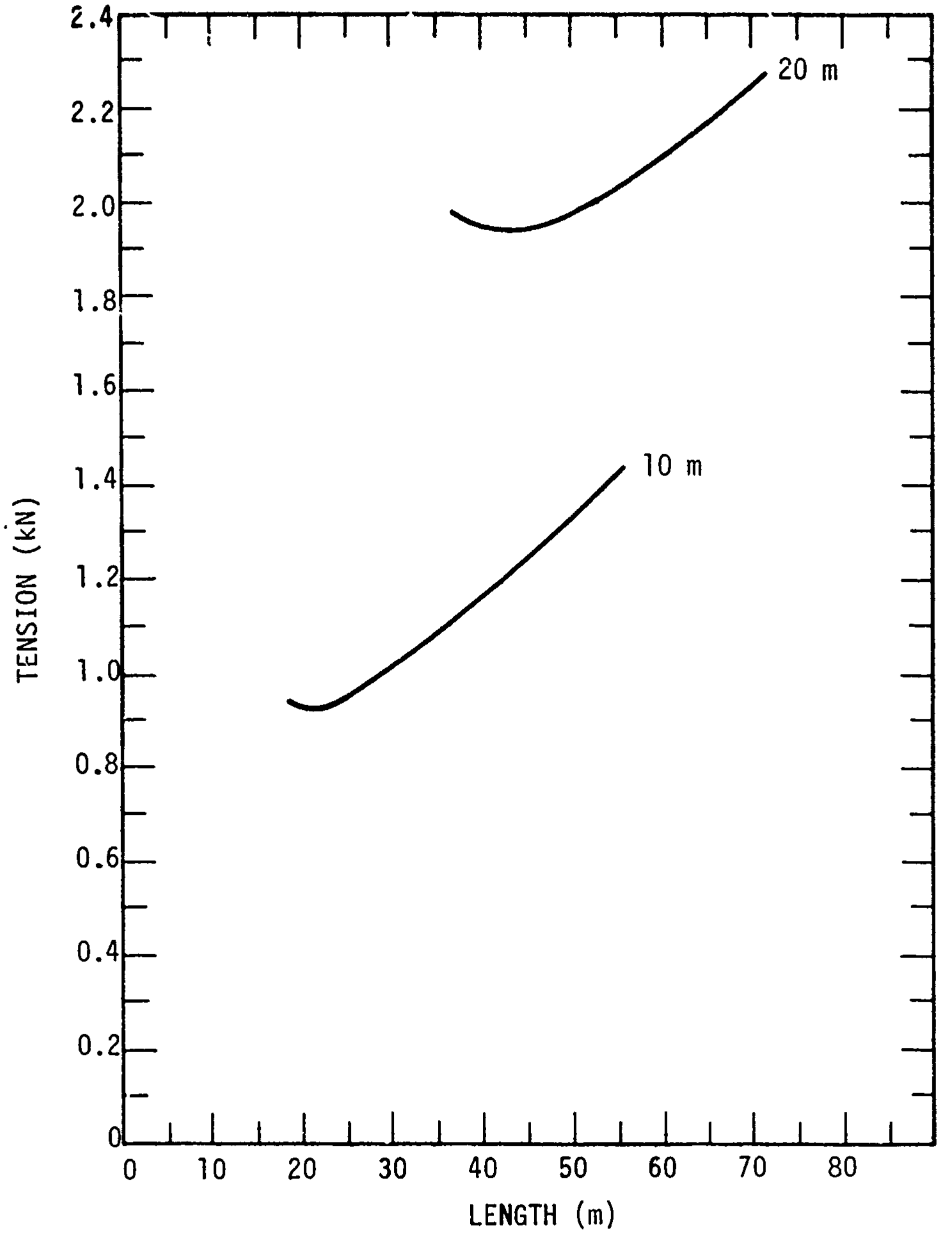


Figure 2 - Predicted Tension in Remote Sensor Cable at 10 Knots as a Function of Cable Length for Two Remote Sensor Distances Above Depressor

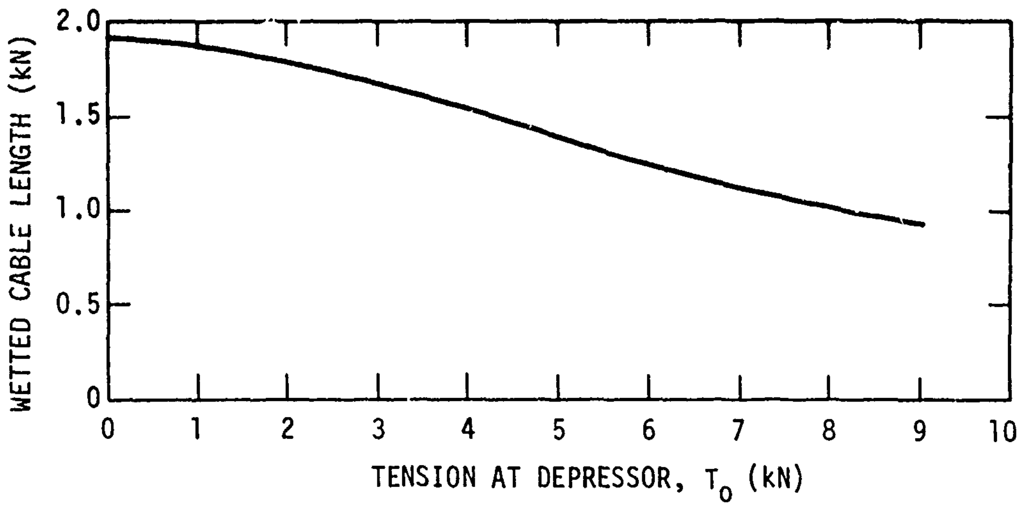


Figure 3a - Wetted Towcable Length

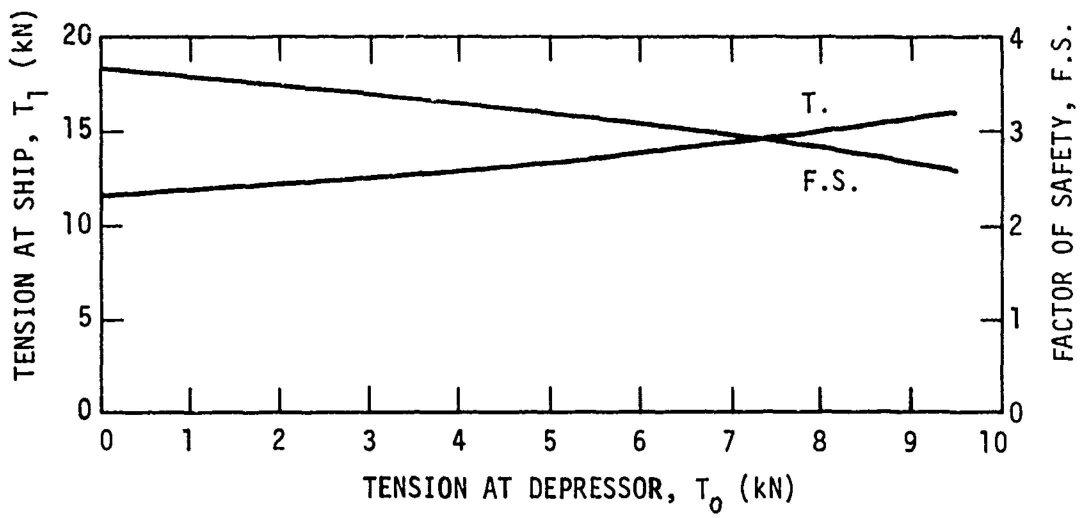


Figure 3b - Towcable Tension

Figure 3 - Predicted Towcable Length and Towing Tension to Achieve a Depth of 200 Meters at 10 Knots as Functions of the Tension Produced by the Depressor (Depressor Lift-to-Drag, L/D = 4.0)

also is shown is Figure 3. The predictions include the effects of the drag imparted by the remote sensor cables; the depressor is assumed to have a lift-to-drag ratio of 4.0 The calculations indicate that a depressor force of 9 kN at 10 knots will maintain a cable factor of safety of 2.7. For this depressor force, a towcable wetted length of 920 m is predicted to achieve the maximum operational depth of 200 m.

The ultimate selection of cable factor of safety must be based on judgment of the relative importance of conflicting goals. A small factor of safety will reduce usable cable life and increase the chances of cable breakage. An excessive factor of safety (low tensile stress) at a given towing speed will decrease the towing depth or require a longer towcable length. For the system under consideration, a large factor of safety also will cause more undesirable variation in the relative vertical separations of the remote sensors during cyclic control. If the towcable is properly maintained and the towing tension is continuously monitored, a factor of safety of 2.7 at a speed of 10 knots should be adequate, although certainly not excessive. If a higher factor of safety is desired, towing speed can be reduced without sacrificing other performance parameters. With a design factor of safety of 2.7 at 10 knots, reducing speed to 8 knots will increase this margin to 4.2.

A low-drag cable fairing such as manufactured by Fathom Oceanology, Ltd. in Canada could be expected to substantially enhance towing performance. Calculations indicate that, for the same towing tension, only 275 m of towcable would be required to achieve a depth of 200 m. A towcable of this type, however, would make attachment of remote sensors more difficult and also would require special and, therefore, expensive handling equipment.

DESCRIPTION OF EQUIPMENT

Not including the CTD instrumentation and the associated remote sensor cables, the towing system consists of four major pieces of equipment: the depressor, the towcable, the two remote sensor mounts, and the control electronics. Guidelines for operation and maintenance of the equipment are given in Appendix B. Design drawings for the mechanical equipment and control electronics are contained in Appendices C and D, respectively. The equipment is described below.

DEPRESSOR

The depressor design is based on an existing depressor developed by DTNSRDC for airborne minesweeping applications. A sketch of the depressor showing principal dimensions is presented in Figure 4. Physical characteristics are listed in Table 1.

The depressor consists of a cylindrical fuselage with a disc-ogive nose and squared-off tail, a biplane box wing cell located approximately at the mid-body, and a cruciform stabilizing fin arrangement aft. The wings, stabilizing fins, and aft half of the fuselage are constructed of glass-reinforced plastic. The pressure housing for control and CTD electronics are fabricated from 6061-T6 aluminum alloy. An interior strongback which supports the wings and CTD pressure housing and provides the towing bracket also is constructed of 6061-T6 aluminum alloy. Connecting hardware is stainless steel.

The pressure housing for the CTD electronics comprises the fuselage forward of the wings. The internal space is 152.4 mm in diameter and 558.7 mm long; however, the forward 20 mm of length is filled with lead ballast leaving a usable length of approximately 538 mm. The housing separates at the aft bulkhead. The forward bulkhead, which also represents the nose of the fuselage, is welded in place. The support for the depressor-attached CTD sensors is mounted to the aft bulkhead. The CTD housing is designed to survive a depth of at least 1.2 km.

Depressor depth control is achieved by the action of a movable flap on the horizontal stabilizer. The flap is driven by a servo motor through a bell-crank linkage. The pressure housing for the control electronics is located inside the fuselage at the aft end of the body. The control system housing also is designed to survive a depth of 1.2 km.

In addition to depth control, the depressor incorporates a passive roll-trim device to counteract any built-in lateral asymmetries. The roll-trim device consists of a weighted pendulum which actuates a trim tab on the vertical stabilizer to produce a depressor rolling moment in the direction of zero roll.

TOWCABLE

The towcable, manufactured by Rochester Corporation as a stock item (without the fairing), is a double-armored cable containing nine electrical conductors. The cable has an overall diameter of 8.8 mm (0.347 in.), a weight in air of 2.87 N/m of length,

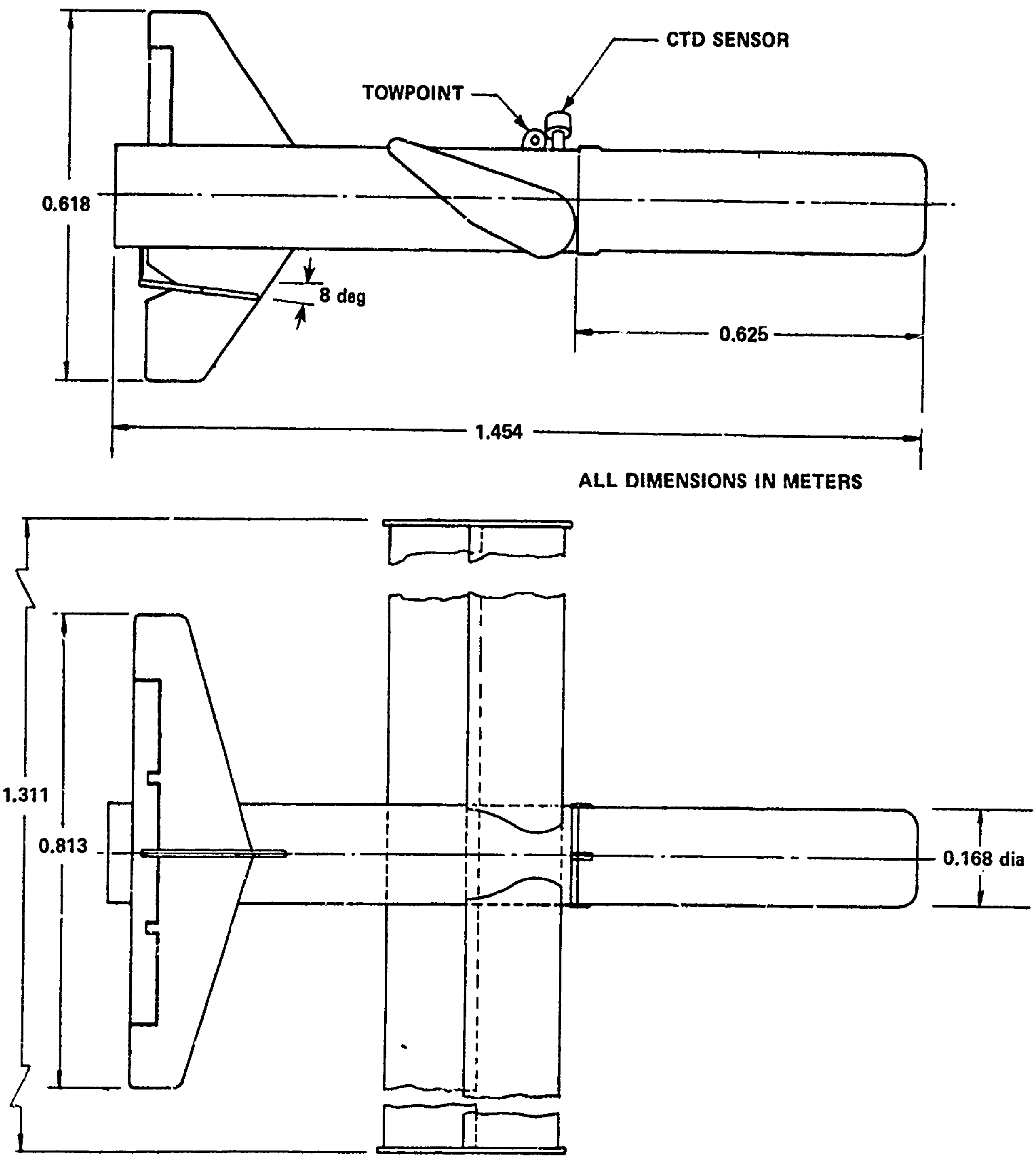


Figure 4 - Depressor

TABLE 1 - DEPRESSOR PHYSICAL CHARACTERISTICS

Overall Characteristics	
Length, m	1.454
Width, m	1.311
Height, m	0.618
Weight in Air*, N	427.0
Weight in Sea Water*, N	136.6
Pitch Trim in Air*, deg	+5.5**
Pitch Trim in Sea Water*, deg	-5.0 (Approx)
Fuselage	
Length Overall, m	1.454
Length CTD Space, m	0.538
Outside Diameter Aft, m	0.171
Outside Diameter Fwd, m	0.168
Diameter CTD Space, m	0.152
Wing	
Configuration	Biplane
Element Section Shape	Cambered Plate
Camber Ratio	0.125
Span, m	1.295
Element Chord, m	0.171
Total Area, m^2	0.444
Vertical Tail	
Section Shape	Flat Plate
Span, m	0.618
Root Chord, m	0.260
Tip chord, m	0.102
Total Area, m^2	0.126
Horizontal Tail	
Section Shape	Flat Plate
Span, m	0.813
Root Chord, m	0.214
Tip Chord, m	0.089
Total Area, m^2	0.123
Control Flap Area, m^2	0.025

*With simulated CTD electronics, 44.5N weight.

**Positve (+) sign indicates nose up.

and a minimum breaking strength of 42.3 kN. Construction of the towcable is illustrated by schematic cross section in Figure 5. Construction is as follows:

1. Conductors - a single #18 American Wire Gage (AWG) tinned copper conductor in a 0.58 mm (0.023 in.) polypropylene insulation at the center of the cable surrounded by eight #22 AWG tinned copper conductors each in a 0.30 mm (0.012 in.) polypropylene insulation. Direct current (dc) resistance of the #18 and the #22 conductors are 21.69 and 55.45 ohms (Ω) per kilometer, respectively. The conductor bundle is held together by a mylar binder tape under a rayon braided jacket.

2. Double Armor - eighteen-wire, 0.91 mm (0.036 in.) diameter per wire inner armor and twenty-four-wire, 0.91 mm (0.036 in.) diameter per wire outer armor, both galvanized improved plow steel.

3. Ribbon Fairing - polyurethane strips 152 mm long, 11 mm wide, and 0.3 mm (0.012 in.) thick applied in-line at a rate of 79 ribbons per meter for 120 m starting at the depressor end of the cable.

The total towcable length is approximately 1.22 km; this length will allow several cable wraps to be left on the handling winch during towing. The cable is mechanically terminated at the depressor end by a standard clevis-type, stainless-steel socket manufactured by Electroline Products. A 3/8 in. (9.5 mm) size is used. The termination is potted to the cable using a Shell 828/Versimide V40 epoxy matrix.

REMOTE SENSOR MOUNT

The remote sensor mount provides a method of placing CTD sensors at various locations along the towcable. The mount is designed to locate the sensors forward of the towcable as shown in Figure 6. The mount is fabricated from 6061-T6 aluminum alloy. It is attached to the cable by an integral brass clamp. The method of attachment is shown in Figure 7.

The mount is design to freely pivot $\pm$ 47 deg with respect to a plane normal to the towcable axis as well as to pivot completely around the axis of the towcable. Directional towing stability is provided by the drag of the remote sensor cable which is attached to the aft end of the mount. During towing the remote sensor mount will align with the axis of the remote sensor cable loop. The remote sensor cables are secured at the depressor by a bracket which clamps to the towcable.

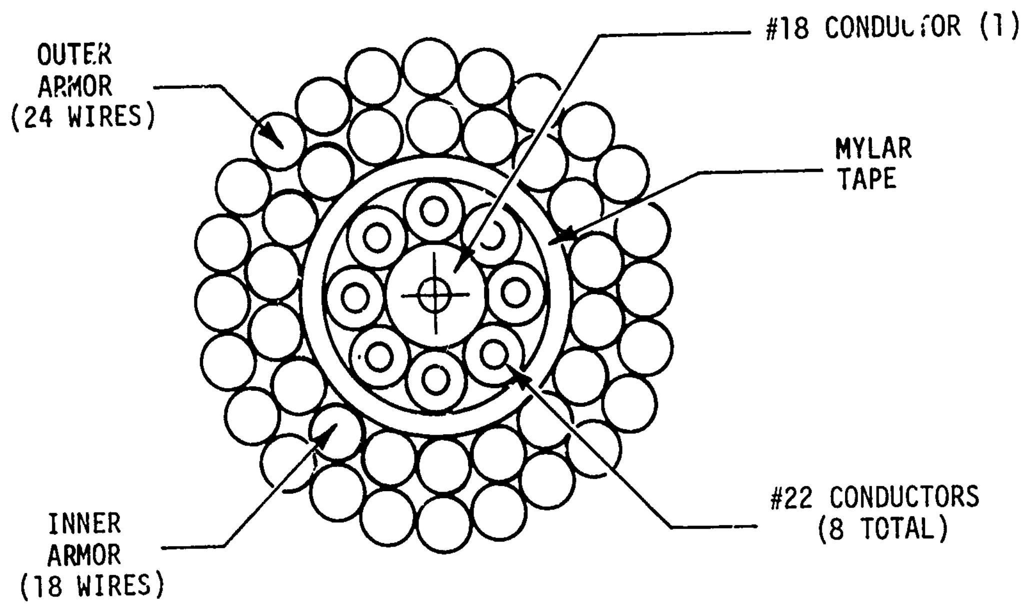


Figure 5 - Schematic Cross Section of Towcable

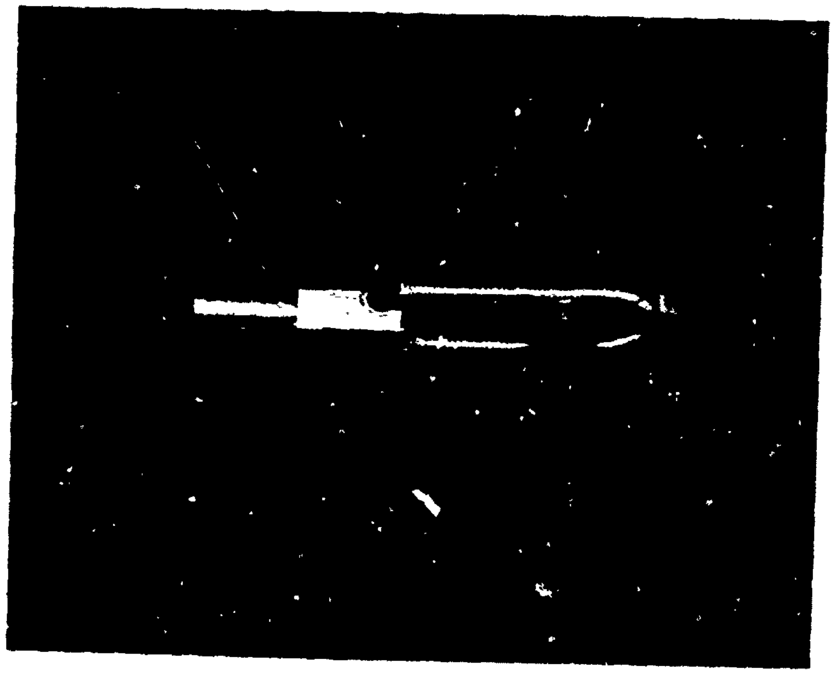


Figure 6 - Remote Sensor Mount

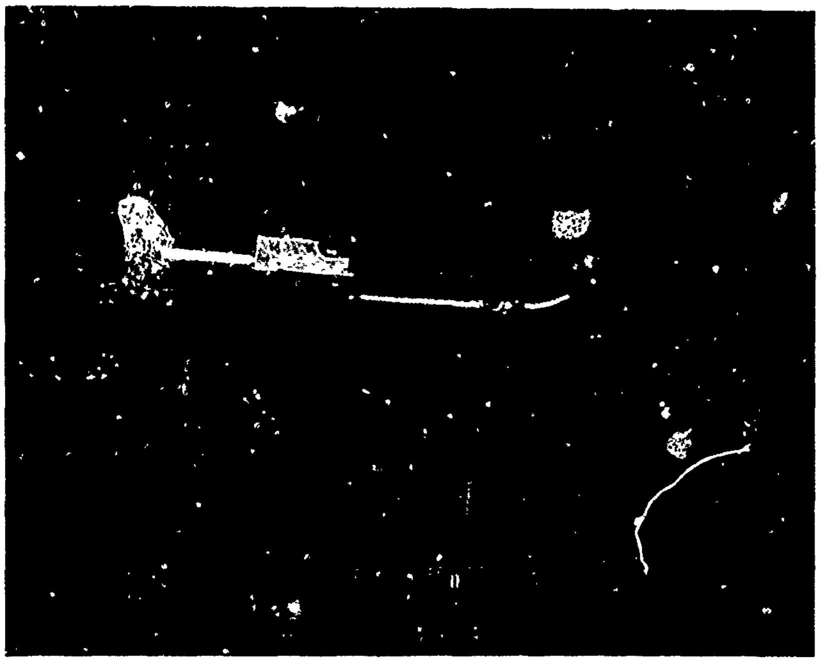


Figure 7a - Prior to Assembly

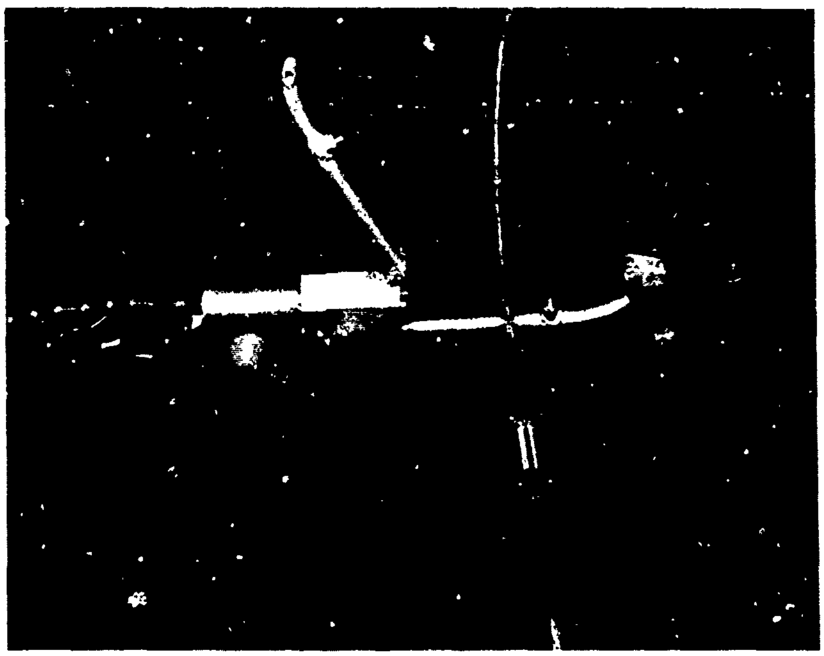


Figure 7b - After Assembly

Figure 7 - Attachment of Remote Sensor Mount to Towcable

DEPTH CONTROL SYSTEM

The depth control system consists of four instruments: an in-body, watertight housing containing a depth-keeping servo; a shipboard control unit; a regulated direct current (dc) power supply, Kepco Model JQE 55-2(M) VP; and a voltage function generator, Hewlett Packard Model 3310A. Diagrams of the circuitry and cabling are contained in Appendix C, DTNSRDC Drawing C-588-1 and 2.

The in-body instrument housing contains a servo-motor which actuates the horizontal tail flap to vary the depth of the depressor. The servo motor is powered from an amplifier where the input comprises the sum of three signals including: depth (from a pressure gage mounted in the bulkhead of the instrument housing), flap angle (from a potentiometer geared to the servo-motor shaft), and ordered depth which is remotely adjusted aboard ship and wired to the instrument housing by one lead within the towcable. The instrument housing also contains circuitry to allow for a remotely controlled electrical calibration of these sensors. A leak director in the housing will sense any water leaks. If there is a water leak, a series of positive voltage blips will appear on the graphic recording of the depth signal. The underwater housing also included three series voltage regulators; one negative 12 V, one positive 12 V, and one high current positive 12 V regulator for the servo-motor and power amplifier.

The shipboard control unit, shown in Figure 8, contains operational amplifiers and circuitry for signal conditioning of the depth and flap angle, a summing network to control depressor depth from the RANGE SWITCH, the RANGE VERNIER potentiometer, and the external oscillator. One operational amplifier is used to control the voltage output of the external power supply so that the output voltage will increase by 30 V when the servo-motor is actually running. When the servo-motor is running, the required current drain from the power supply is approximately 1.3 A; the round-trip resistance of the power leads in the 1.2 kN length of towcable is approximately 30 Ω, which results in a voltage loss in the towcable of 45 V. A shunt regulator across the external power supply (B^+) inside the in-body instrument housing is used to suppress transients in the towcable due to servo-motor surge.

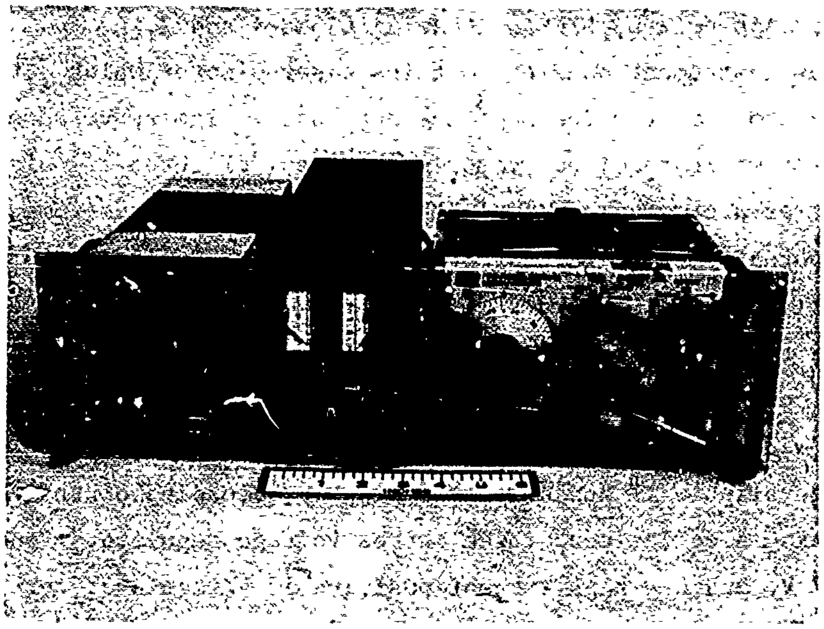


Figure 8 - Shipboard Control Electronics

The control unit contains four positive and negative 15 V dc power supplies, as shown on DTNSRDC Drawing C-508-1 in Appendix D. Power supply C provides power to operational amplifier P1; the common lead is at a potential above ground equal to the positive out of the Kepco power supply. Power supply B furnishes negative 30 V to the depressor instrument housing via one lead and ground of the towcable. A momentary depression of the CAL START switch parallel with the Zener diode causes a 5 V decrease in the negative 30 V output which starts the electrical calibration sequence within the depressor instrument housing. The sequence is ZERO CHECK (ZC), CAL 1 (C1), and CAL 2 (C2). Power supply A provides power to all the operational amplifiers denoted N&O and the common lead is connected to the depressor instrument housing ground and isolated from the control unit ground. Power supply D supplies power to the operational amplifier denoted by S and the common is tied to the control unit ground. The control unit front panel contains four controls; an ON-OFF power switch, a CAL START pushbutton switch, a RANGE SWITCH, and a RANGE VERNIER 10-turn potentiometer. The ON-OFF power switch controls the power to the four positive and negative power supplies in the control unit. The CAL-START switch is used to start the electrical calibration sequence for the depth and flap measurements. The RANGE SWITCH is used to set the desired depth of the depressor in 100-m increments. The RANGE VERNIER potentiometer allows for fine adjustment of the depressor depth. Ten full turns of this control is equivalent to 105 m of depth; the smallest increment on the dial is equivalent to 1/500 of full scale or 210 mm.

The Kepco power supply provides the positive voltage to the depressor instrument housing electronics.

The Hewlett Packard Function Generator is incorporated into the system to dynamically control the depth of the depressor through a range of frequencies and amplitudes.

BASIN EVALUATION

Evaluations were conducted in the deep-water basin at DTNSRDC to examine towing charactertistics of the depressor and operation of the control electronics. Evaluations with active control were severely limited since the towcable length, by necessity, was short and in no way representative of an operational configuration. Therefore, depressor depth response to dynamic flap input could not be determined directly.

However, basin experiments did provide some qualitative indication of depressor behavior and did verify towing forces. The equipment, procedures, and results are discussed below.

EQUIPMENT

Mechanical equipment consisted of a 4.5 m length of the standard towcable, a swivel located at the upper end of the towcable, and a variable depth towing strut.

Instrumentation consisted of the following:

1. A 17 8-kN (4000-lb) capacity strain-gage load cell with an estimated overall accuracy of $\pm$ 90 N located at the towing strut for measurement of towing tension;
2. A magnetic pickup on the towing carriage to provide measurements of speed to an accuracy of $\pm$ 0.01 knot;
3. The standard control electronics which provided measurements of body depth and control flap angle; and
4. A six-channel strip-chart recorder to provide readout of tension, speed, depth, and flap angle.

PROCEDURES

Initially the depressor was towed without active control to examine passive towing behavior and to establish a satisfactory trim condition. The incidence angle of the horizontal stabilizer (with respect to the fuselage centerline) was varied between 6 and 8 deg (leading edge down), the control flap angle was varied between $\pm$ 20 deg, and towing speed was varied between 5 and 10 knots. Towing tension, speed, and visual towing behavior were the only functions monitored during this series of experiments.

Following selection of a suitable stabilzer incidence angle, the depressor was towed with active control. Both square and sine wave control inputs were examined. The square wave inputs were primarily intended to investigate depressor control stability. A square wave with a period of 28 sec and a nominal flap amplitude of $\pm$ 13 deg was used. This allowed observation of active control towing behavior at both high and low tension conditions. During this experiment, the control flap gain (the flap angle response per unit change in depth) was changed from a nominal value of 19.7 deg/m to 6.6 deg/m. The sine wave control input was intended to examine the

depressor tension response. A sine wave with a period of 28 sec and a nominal flap amplitude of $\pm$ 17 deg was selected as a severe test; most operational conditions will not require this range of flap angles to obtain the desired cyclic depth variation.

RESULTS

Without active control, the depressor towed in an acceptable manner at all speeds and stabilizer settings. Initially some erratic yawing motions of the depressor, apparently generated by oscillations of the passive roll-trim device, were noted. This was corrected by increasing the chord of the trim tab slightly to shift the center of hydrodynamic pressure aft relative to the tab pivot axis. Results of the steady towing experiments are presented in Table 2 which shows the cable tension (corrected to standard sea conditions) and the coefficient of tension C_T for the range of stabilizer and control flap incidence angles investigated. The coefficient of tension C_T is defined as

$$C_T = \frac{T_o}{1/2 \rho V^2 S} \tag{3}$$

where T_o is cable tension at the depressor,

ρ is fluid density,

V is towing speed, and

S is wing projected area.

The coefficient of tension as a function of control flap deflection is plotted in Figure 9 for various speeds and stabilizer incidence angles. This figure indicates that a stabilizer incidence angle of -8 deg (leading edge down) will provide the widest range of depressor tension coefficients. This angle, therefore, was selected as the most suitable.

Response of the depressor to a square wave control input is shown in Figure 10 for two flap gain values. The damping of the response at the lower tension condition appears to be improved with the lower flap gain value. At the higher tension condition, the response is critically damped for both flap gain values. These responses are influenced by towline length and therefore will change somewhat with a longer towline; however, the trends probably are indicative.

TABLE 2 - BASIN EVALUATION DATA

Run	Speed (knot)	Tail Angle (deg)	Flap Angle (deg)	Tension (kN)	C_T
1	5.0	-6.0	+4	2.28	1.51
2	8.0	-6.0	+4	5.67	1.47
3	8.0	-6.0	0	5.17	1.34
4	10.0	-6.0	0	7.88	1.31
5	5.0	-6.0	-10	1.49	0.98
6	8.0	-6.0	-10	3.60	0.93
7	10.0	-6.0	-10	5.62	0.93
8	5.0	-6.0	-15	1.14	0.76
9	8.0	-6.0	-15	3.02	0.78
10	10.0	-6.0	-15	4.76	0.79
11	5.0	-6.0	-20	1.05	0.70
12	8.0	-6.0	-20	2.33	0.60
13	10.0	-6.0	-20	3.66	0.61
14	5.0	-6.0	-23	1.12	0.74
15	8.0	-6.0	-23	2.35	0.61
16	9.9	-6.0	-23	3.54	0.59
17	8.0	-7.0	0	4.78	1.24
18	10.0	-7.0	0	7.32	1.21
19	5.0	-7.0	-10	1.35	0.89
20	8.0	-7.0	-10	3.18	0.82
21	10.0	-7.0	-10	4.93	0.82
22	5.0	-7.0	-15	0.94	0.62
23	8.0	-7.0	-15	2.15	0.56
24	10.0	-7.0	-15	3.45	0.57
25	5.0	-7.0	-20	0.80	0.53
26	8.0	-7.0	-20	1.60	0.41
27	10.0	-7.0	-20	2.52	0.42
28	5.0	-7.0	-22	0.89	0.59
29	8.0	-7.0	+10	5.83	1.51

TABLE 2 (Continued)

Run	Speed (knot)	Tail Angle (deg)	Flap Angle (deg)	Tension (kN)	(C_T)
30	10.0	-7.0	+10	8.91	1.48
31	5.0	-7.0	+15	2.52	1.67
32	8.0	-7.0	+15	5.96	1.54
33	10.0	-7.0	+15	9.23	1.53
34	5.0	-7.0	+20	2.56	1.69
35	8.0	-8.0	0	4.20	1.09
36	10.0	-8.0	0	6.50	1.07
37	5.0	-8.0	-10	1.14	0.76
38	8.0	-8.0	-10	2.52	0.65
39	10.0	-8.0	-10	4.11	0.68
40	5.0	-8.0	-15	0.66	0.44
41	8.0	-8.0	-15	1.57	0.41
42	10.0	-8.0	-15	2.63	0.44
43	5.0	-8.0	-20	0.48	0.32
44	8.0	-8.0	-20	0.89	0.23
45	10.0	-8.0	-20	1.25	0.21
46	5.0	-8.0	+10	2.24	1.49
47	8.0	-8.0	+10	5.40	1.40
48	10.0	-8.0	+10	8.35	1.38
49	5.0	-8.0	+15	2.49	1.65
50	8.0	-8.0	+15	5.85	1.52
51	10.0	-8.0	+15	9.10	1.51
52	5.0	-8.0	+20	2.52	1.67
53	8.0	-8.0	+20	6.06	1.57
54	10.0	-8.0	+20	9.26	1.54
55	5.0	-8.0	+22	2.52	1.67

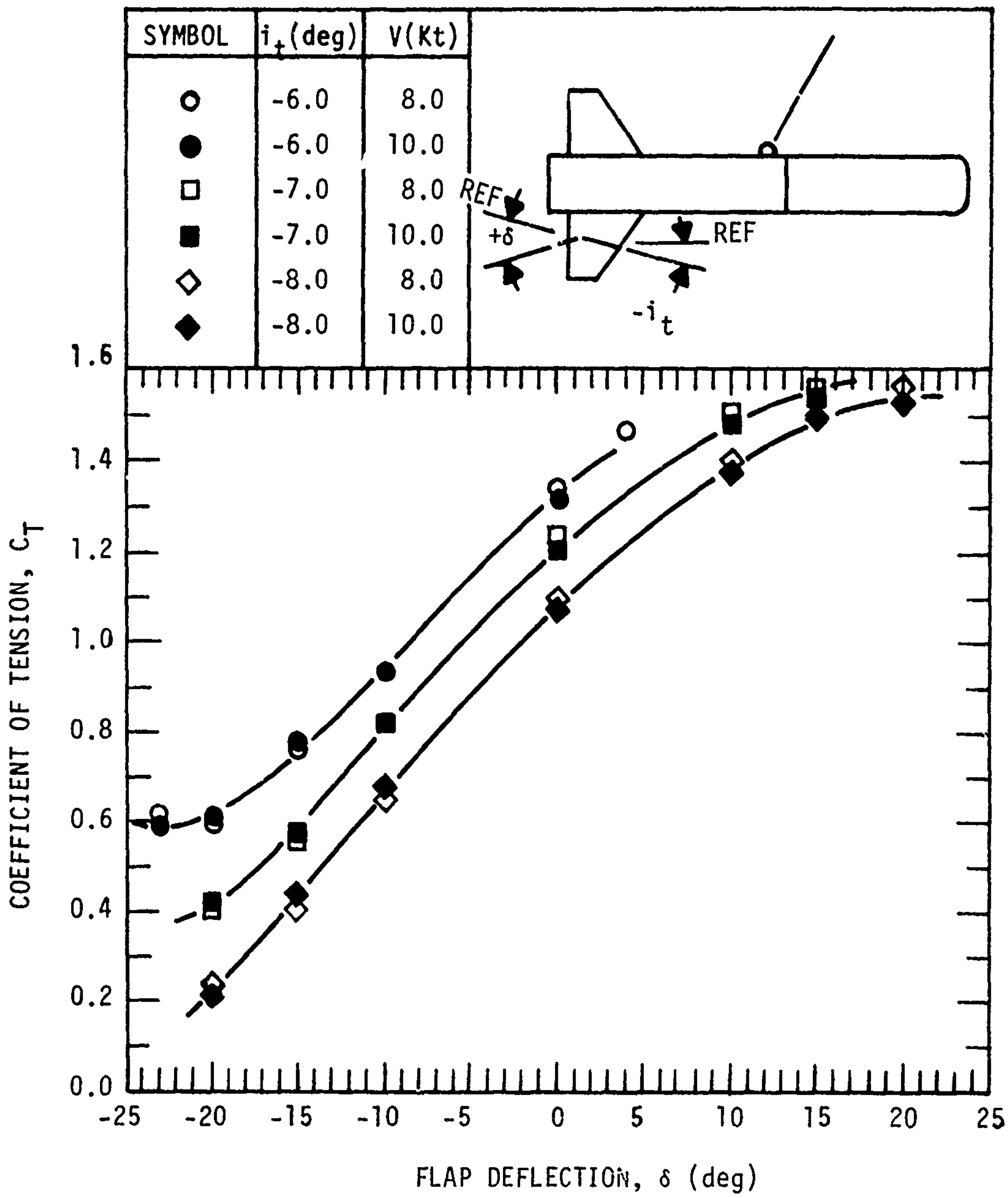


Figure 9 -- Depressor Coefficient of Tension as a Function of Control Flap Deflection for Various Speeds and Horizontal Stabilizer Incidence Angles

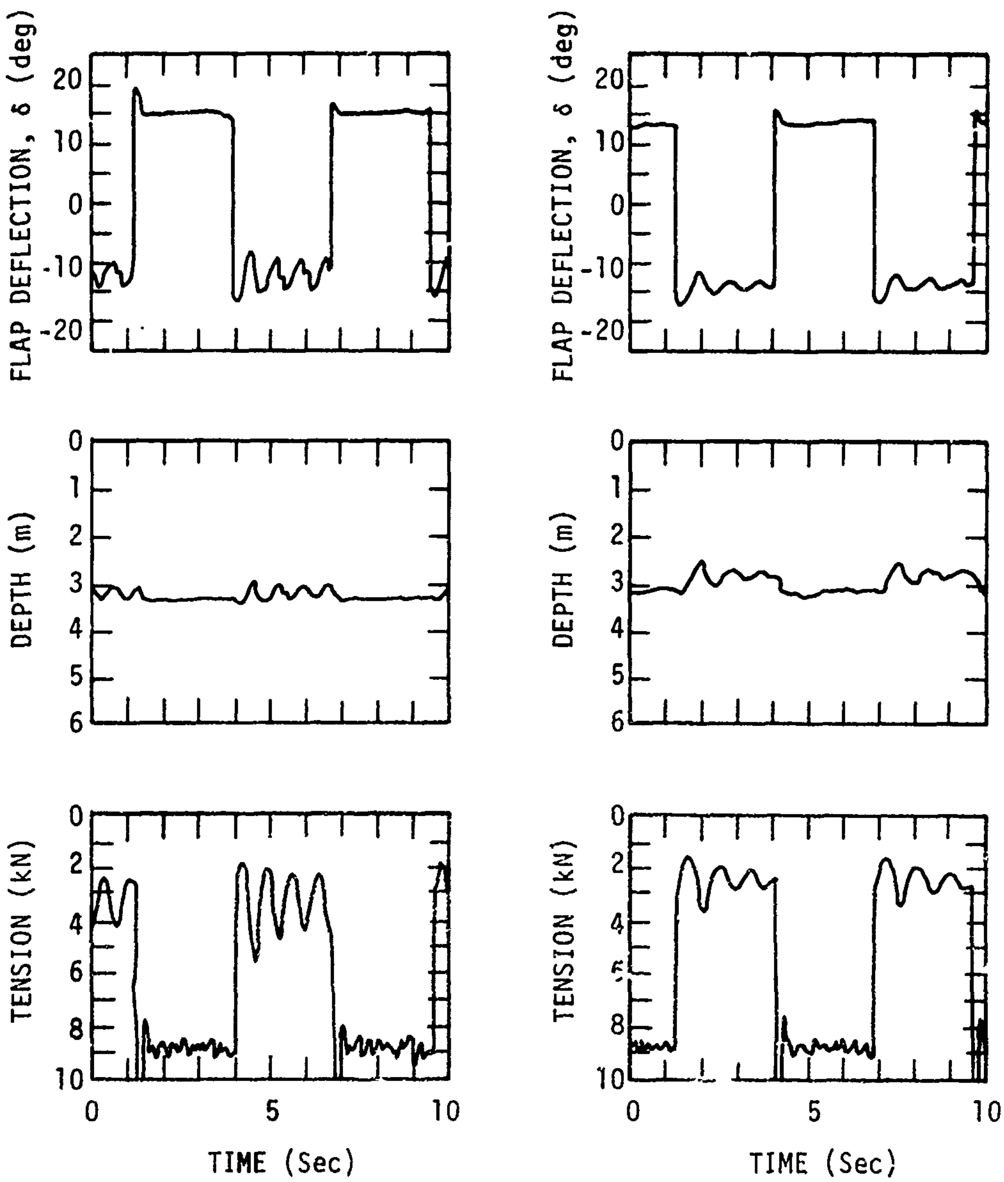


Figure 10a - Flap Grain,
19.7 Degree/Meter

Figure 10b - Flap Grain,
6.6 Degree/Meter

Figure 10 - Depressor Response at 10 Knots to a Square Wave Control Input for Two Flap Gain Values (Towcable Length, 4.5 m)

Response of the depressor (with a flap gain of 6.6 deg/m) to a sine wave control input is shown in Figure 11. The depth response is not meaningful as noted earlier. However, the tension response has very little distortion which indicates that the depressor and control system are performing satisfactorily.

AT-SEA EVALUATION

A one-day, at-sea towing evaluation of the depressor was conducted out of Bermuda in Nov 1979 aboard USNS KANE (AGS-T27) to examine hydrodynamic performance in an operational environment. The CTD electronics were not installed, nor was the performance of the remote sensor mounts examined during the evaluation. The equipment, procedures, and results are discussed below.

EQUIPMENT

Equipment consisted of the following:

1. The depressor ballasted with a 44.5 N weight in the nose to simulate the expected weight of the CTD electronics;
2. The standard towcable;
3. A handling winch provided by NAVOCEANO;
4. An overboarding sheave (suspended below the fantail A-frame) also provided by NAVOCEANO;
5. A towcable clamp to transfer the towing tension from the winch to a hard-point on the ship deck;
6. A 22.2-kN (5000-lb) capacity load cell with an estimated overall accuracy of $\pm$ 100 N located at the cable clamp for measurement of towing tension; and
7. The depressor control electronics which provided depth control as well as measurement of control-flap angle and body depth.

Tension, flap angle, depth, and the difference between initial set depth and actual depth (Delta depth) were recorded on a series of single-channel strip chart recorders provided by NAVOCEANO. Ship speed was obtained from a speed calibration curve based on propeller turning rate.

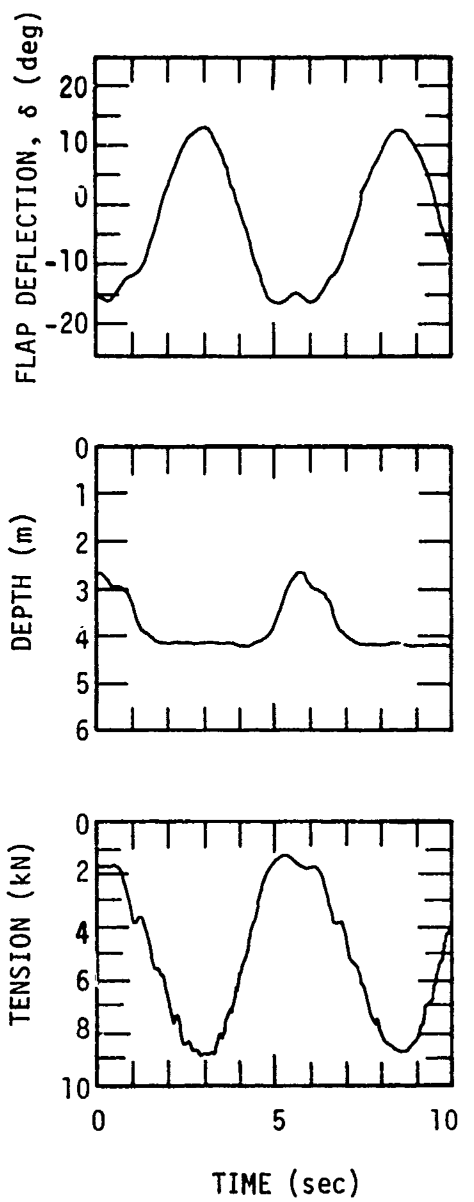


Figure 11 - Depressor Response at 10 Knots to a Sine Wave Control Input (Towcable Length, 4.5 m)

PROCEDURES

Towing performance was exmained at nominal wetted towcable lengths of 850, 250, and 115 m. At each towcable length, the depressor was towed at various set depths to examine the towing behavior corresponding to different depressor lift conditions (flap angle positions). Towing performance was examined primarily at a ship speed of 10 knots although some data were obtained at speeds of 5 and 8 knots also. The depressor was towed with and without cyclic depth control. Oscillator frequencies less than 0.015 Hz were used during most of the profiling runs since the lower frequencies presumably are of primary interest. However, the depressor response also was examined at an oscillator frequency of 0.2 Hz during one run.

Streaming and recovery operations were performed at a ship speed of approximately 3 knots to maintain towcable tension at a low value. This was necessary to prevent the top layer of cable on the winch from burying itself under subsequent layers since the cable had initially been wrapped on the winch with no back tension.

RESULTS

Seas increased from a state 2 at the beginning of the evaluation to a state 3 or 4 during the latter portions. The results of the evaluation are summarized in Table 3. Flap angle, depth, and tension traces from representative profiling runs are shown in Figures 12 through 15.

During all runs, measured depth deviated substantially from set depth. The discrepancy varied from a maximum of approximately 30 m at a set depth of 200 m to 10 m at a set depth of 50 m. Part of the error can be explained by the design of the control system. By design, depth error is zero only at a control-flap deflection of zero; at other flap angles, the error is equal to the flap deflection divided by the flap gain value. This effect, however, accounts for only about 3 m of error. No explanation is provided for the remainder of the discrepancy other than inadequate calibration. Ultimately, depressor depth will be determined using the CTD electronics. Therefore, any depth errors associated with the control electronics are of little concern.

The ability of the depressor to maintain a constant depth is indicated in Table 3 and also in some of the traces of Figures 12 through 14. Generally, as long as the control flap was not fully deflected (as it was during Runs 9 and 10), the depressor maintained a constant depth to within $\pm$ 300 mm. The control flap response

TABLE 3 - AT-SEA EVALUATION DATA

Run No.	Wetted Cable Length (m)	Nominal Set Depth (m)	Towing Speed (knot)	Oscillator		Flap Angle		Depth		Tension	
				Frequency (Hz)	Amplitude	Mean (deg)	Variation (deg)	Mean (m)	Variation (m)	Mean (kN)	Variation (kN)
1	850	0	6.0	0	0	*	*	198	*	2.7	±0.4
2	850	200	6.0	0	0	*	*	235	±0.1	3.8	±0.4
3	850	160	8.1	0.020	**	*	*	190	±8.0	7.0	±2.5
4	850	160	8.1	0	0	*	*	190	±0.3	6.2	±0.9
5	850	200	8.1	0	0	*	*	226	±0.2	6.7	±0.9
6	850	200	10.4	0	0	*	*	210	±0.2	11.6	±1.0
7	250	115	5.4	0	0	*	0	146	±0.1	1.3	±0.8
8	250	115	8.0	0	0	+10	±1	128	±0.3	4.9	±1.1
9	250	115	10.4	0	0	+25	0	122	±0.4	12.3	±1.2
10	250	15	10.4	0	0	-25	0	31	±1.5	4.2	±0.3
11	250	87	8.0	0	0	-2	±1	104	±0.3	5.6	±0.6
12	250	87	8.0	0.0016	Full	0	±10	106	±18.2	6.2	±1.3
13	250	87	10.0	0.0016	Full	-1	±8	107	±18.2	9.9	±2.3
14	250	87	10.0	0.0033	Full	0	±10	107	±18.2	9.8	±2.7
15	250	87	10.0	0.0063	Full	0	±12	107	±18.6	10.0	±3.8
16	250	87	10.0	0.013	Full	+4	±21	106	±18.0	10.2	±5.3
17	250	87	10.0	0.013	1/2 Full	-1	±10	105	±9.4	10.2	±3.1
18	250	107	10.0	0.010	1/2 Full	+11	±14	120	±8.2	10.5	±2.8
19	250	107	10.0	0.010	**	+12	±13	120	±7.3	10.2	±2.3
20	250	130	10.0	0.010	1/2 Full	+3	±9	113	±8.7	10.5	±3.3
21	250	100	10.0	0.20	1/3 Full	+6	±19	113	±0.5	10.4	±2.2
22	115	50	10.0	0.020	1/2 Full	-8	±8	60	±8.5	7.6	±3.1
23	115	60	10.0	0.020	1/2 Full	-3	±11	71	±8.2	9.8	±4.0
24	115	60	10.0	0.020	Full	0	±25	68	±16.8	10.5	±6.7
25	115	50	10.0	0.010	1/2 Full	-10	±6	60	±9.5	7.3	±2.2
26	115	50	10.0	0.0067	1/2 Full	-10	±5	60	±9.0	7.1	±1.8
27	115	60	10.0	0.0067	1/2 Full	-4	±6	66	±8.5	8.6	±2.0
28	115	70	10.0	0.0067	1/2 Full	+12	±8	82	±7.6	10.4	±3.8
29	115	60	10.0	0.0067	Full	0	±14	71	±18.2	9.8	±4.4
30	115	50	10.0	0.0067	Full	-9	±11	60	±18.5	7.5	±3.8
31	115	50	10.0	0.0033	Full	-10	±12	60	±18.5	7.1	±3.1

*Recorder not functioning.

**Value not recorded.

Figure 12 - Depressor Response at 10 Knots to Various Sine Wave Control Inputs (Wetted Towcable Length, 250 m; Depth Set, 87 m)

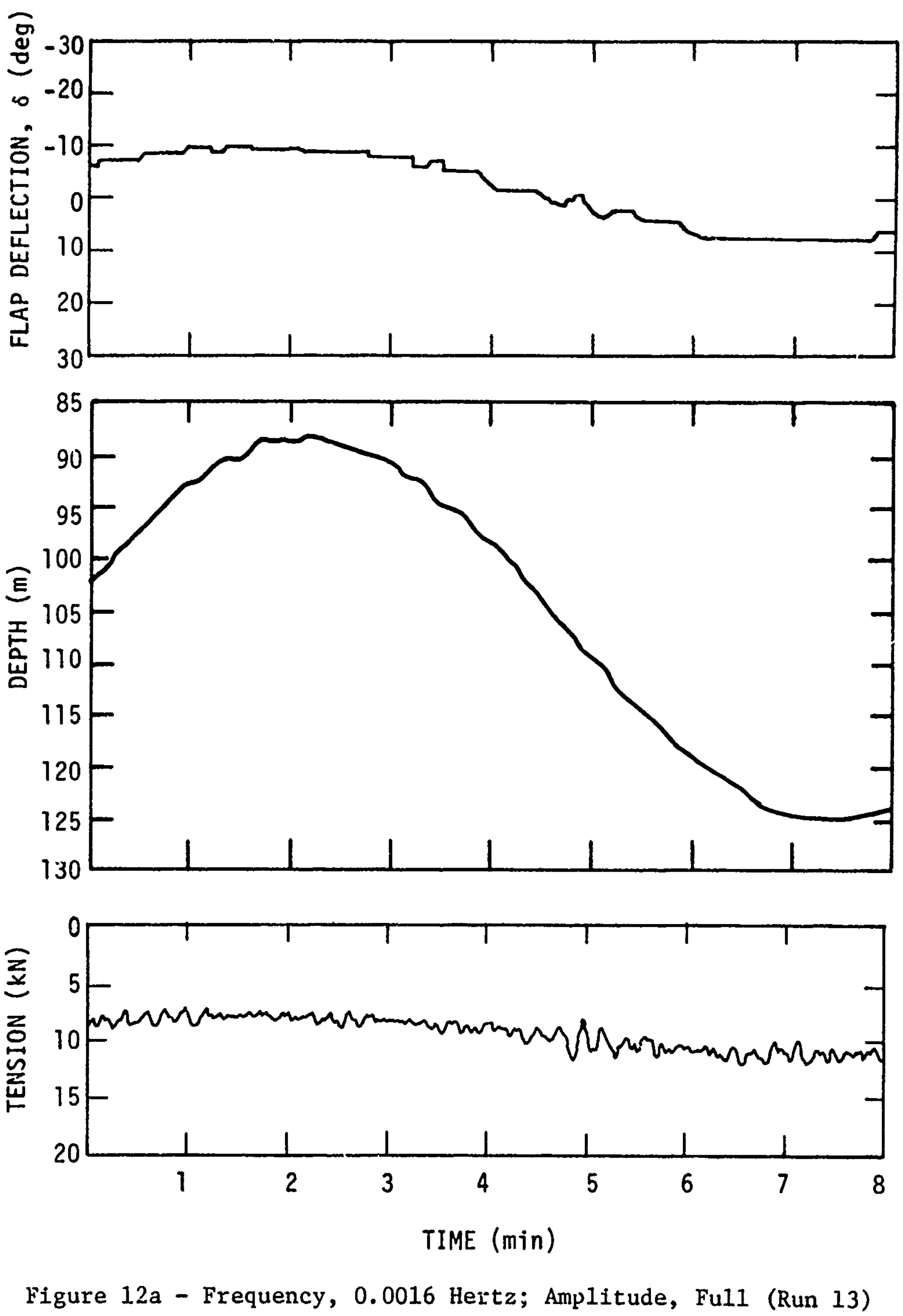


Figure 12a - Frequency, 0.0016 Hertz; Amplitude, Full (Run 13)

Figure 12 (Continued)

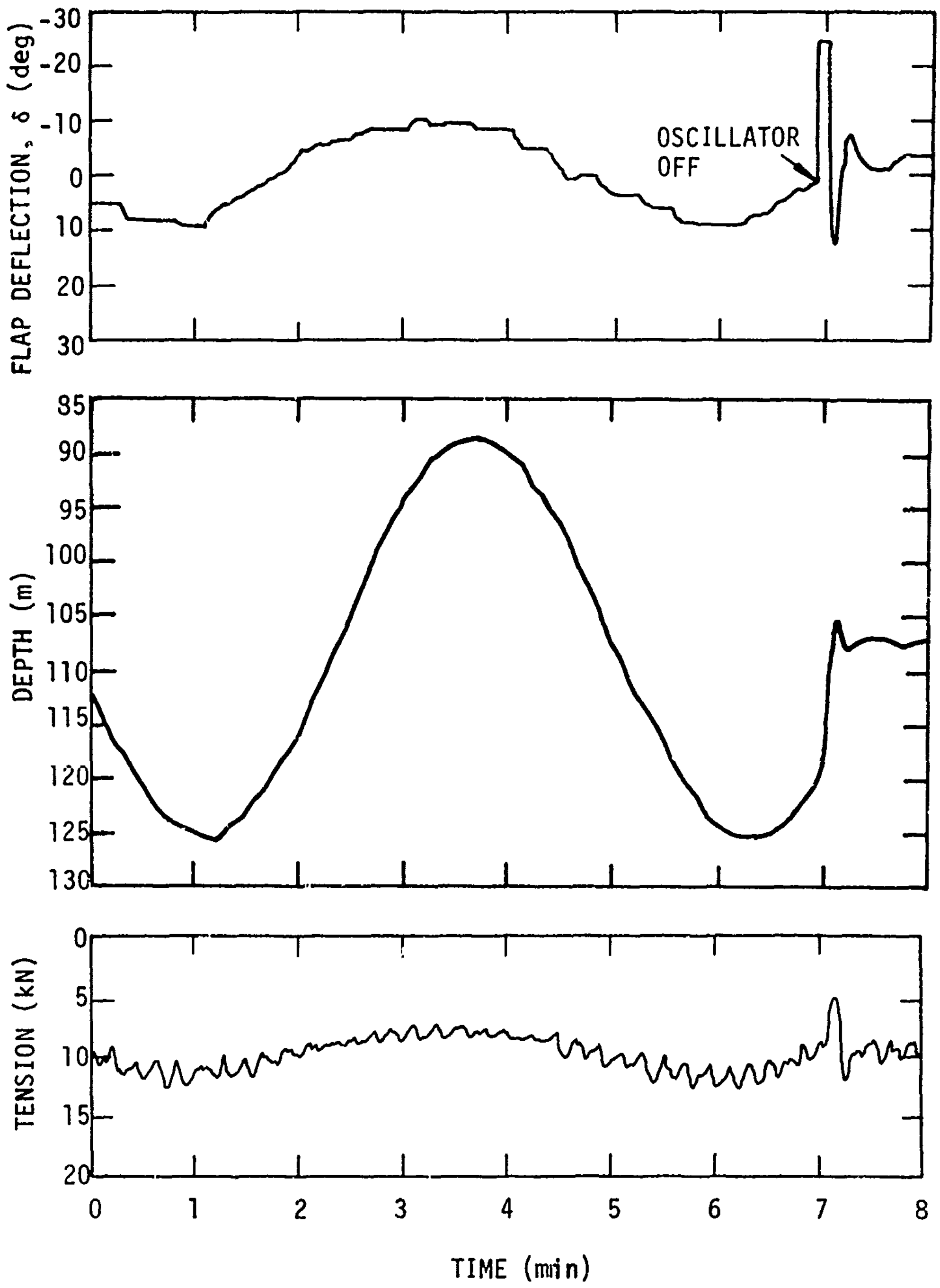


Figure 12b - Frequency, 0.0033 Hertz; Amplitude, Full (Run 14)

Figure 12 (Continued)

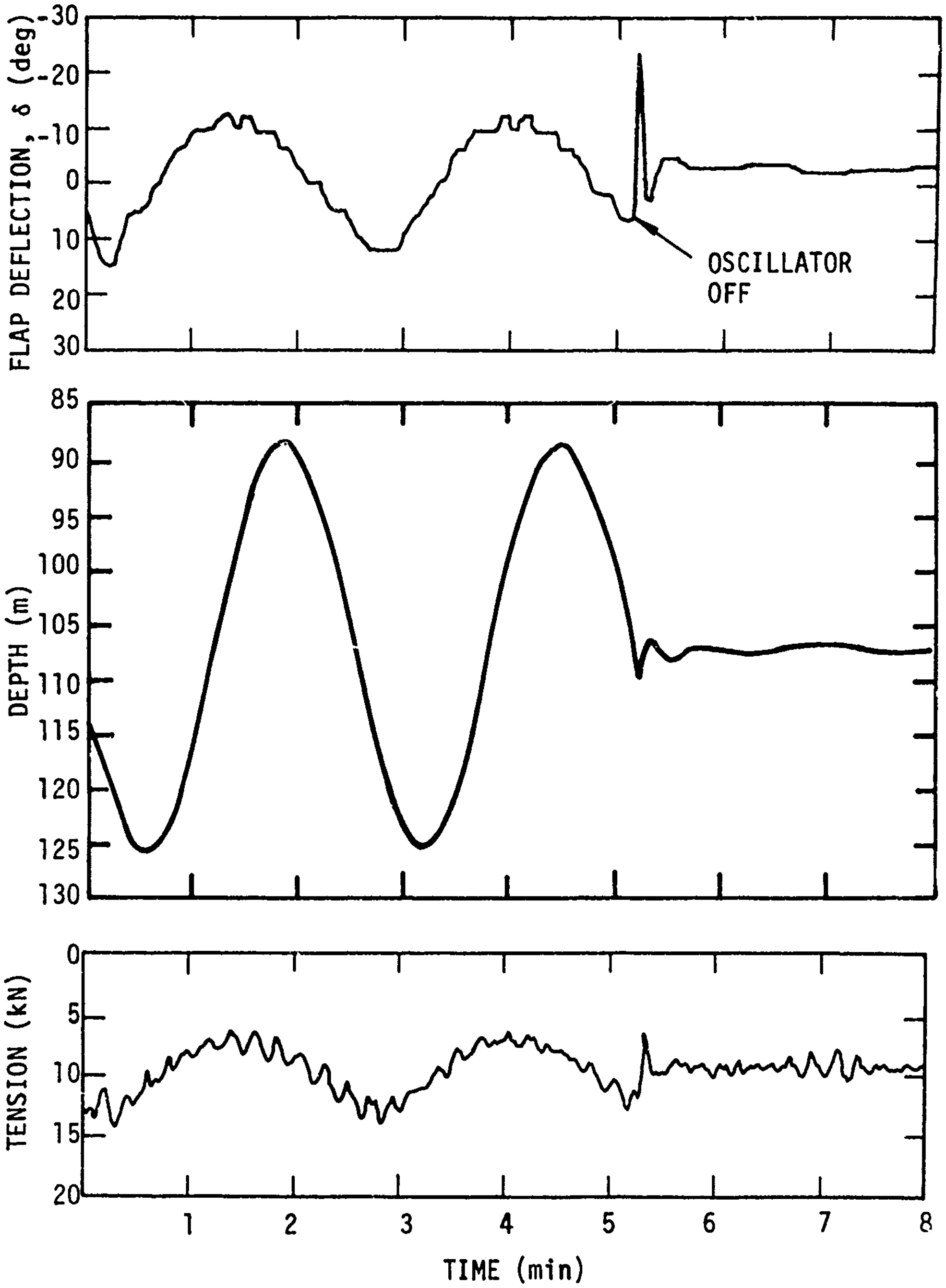


Figure 12c - Frequency, 0.0063 Hertz; Amplitude, Full (Run 15)

Figure 12 (Continued)

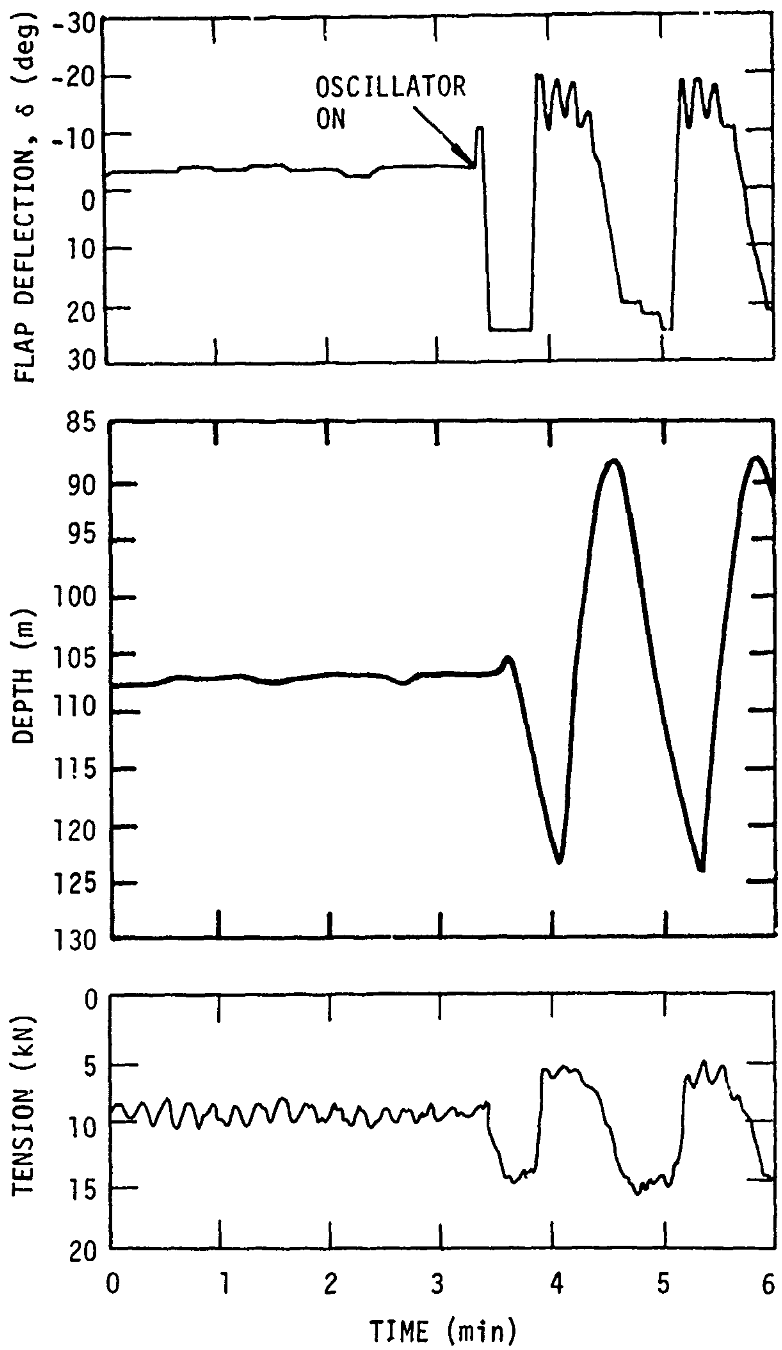


Figure 12d - Frequency, 0.0132 Hertz; Amplitude, Full (Run 16)

Figure 12 (Continued)

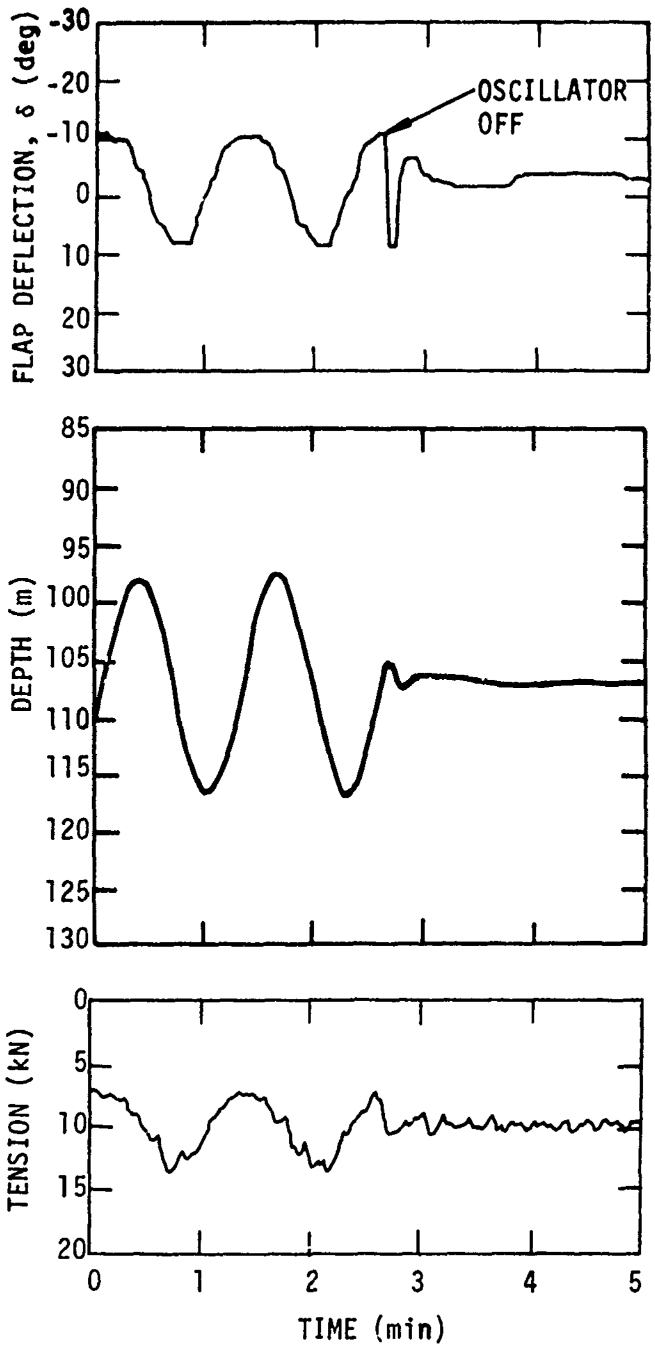


Figure 12e - Frequency, 0.0132 Hertz; Amplitude, Half Full (Run 17)

Figure 13 - Depressor Response at 10 Knots to Various Sine Wave Control Inputs (Wetted Towcable Length, 250 m; Depth Set, 100 m)

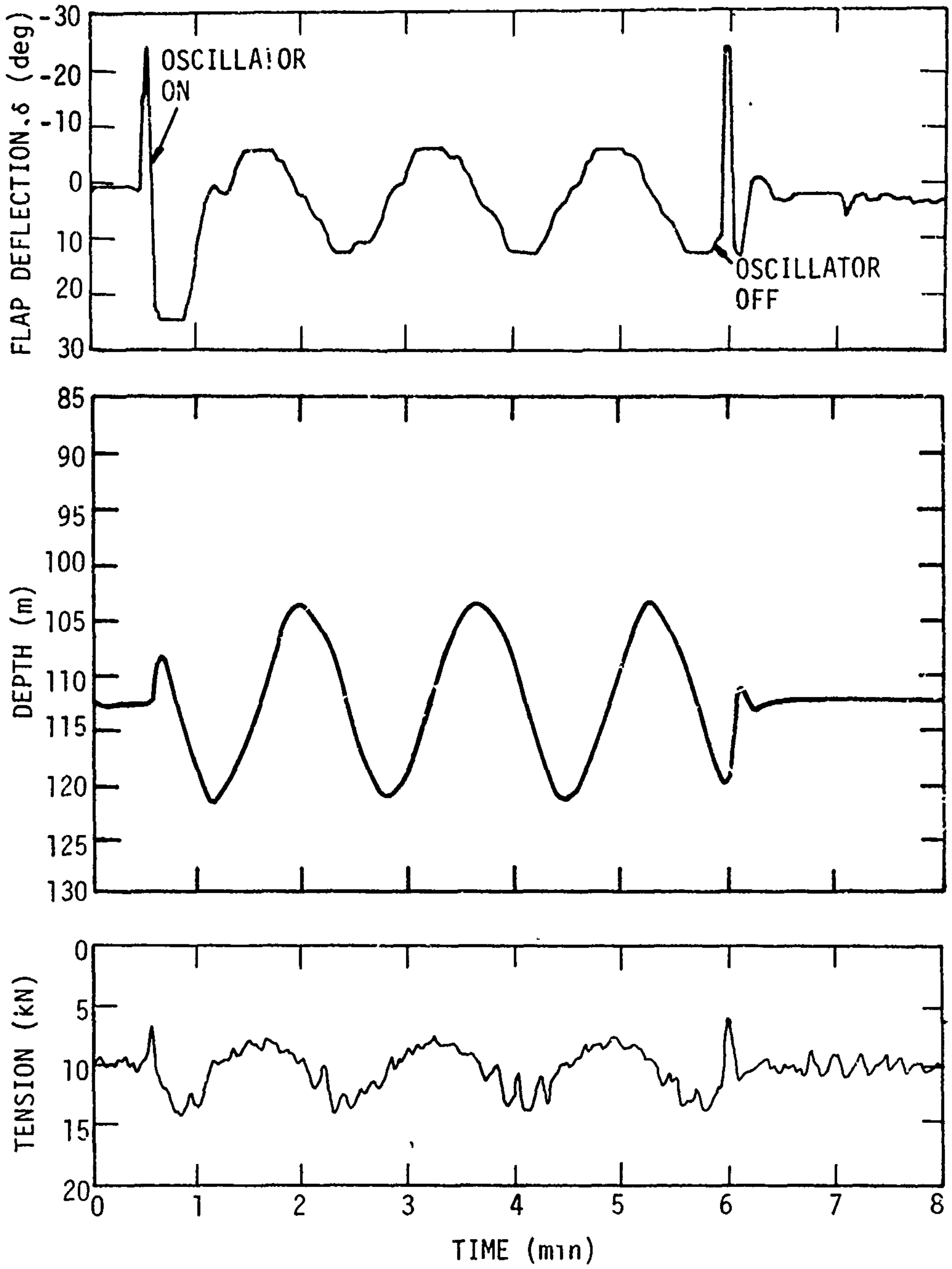


Figure 13a - Frequency, 0.0100 Hertz; Amplitude, Half Full (Run 20)

Figure 13 (Continued)

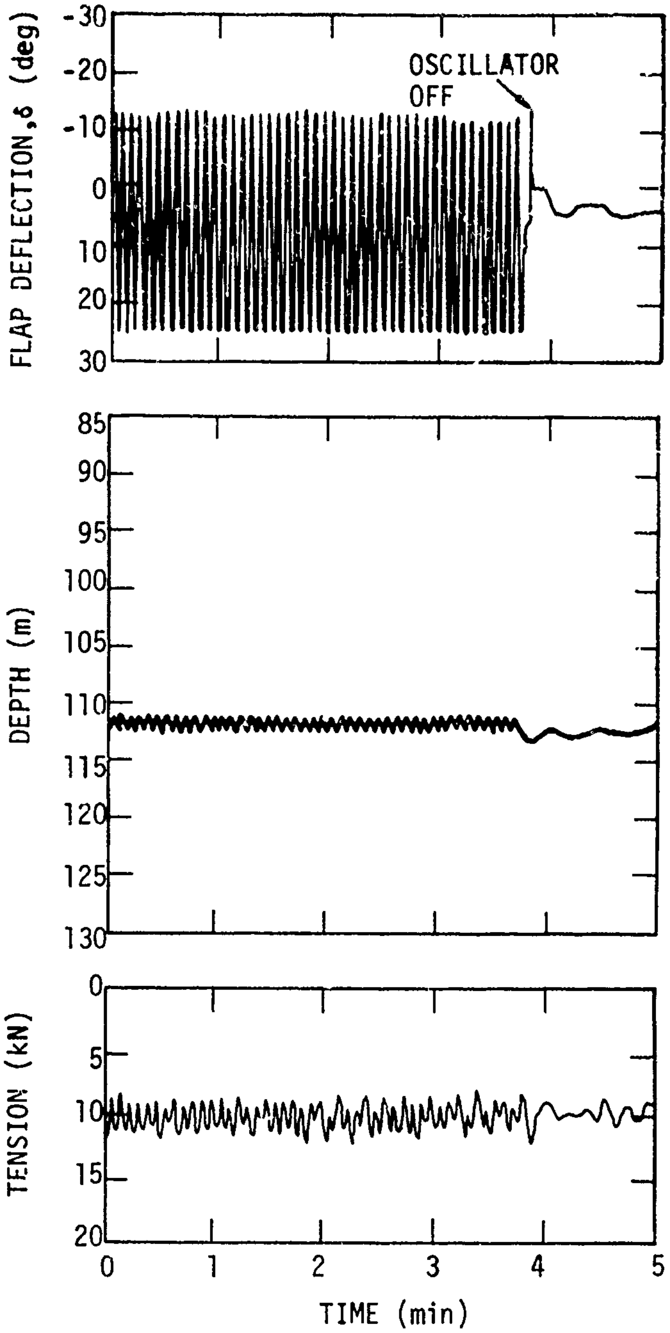


Figure 13b - Frequency, 0.20 Hertz;
Amplitude, One-Third Full (Run 21)

Figure 14 - Depressor Response at 10 Knots to Various Sine Wave Control Inputs (Wetted Towcable Length, 115 m; Depth Set, 50 m)

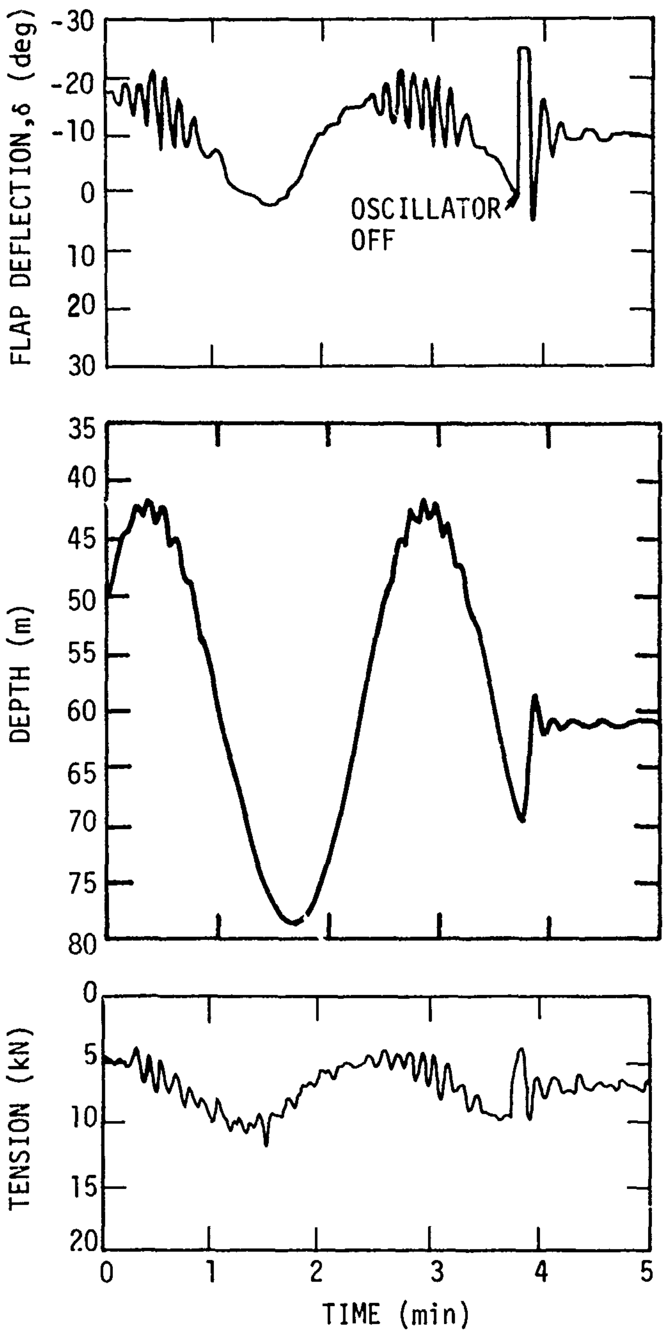


Figure 14a - Frequency, 0.0067 Hertz; Amplitude, Full (Run 30)

Figure 14 (Continued)

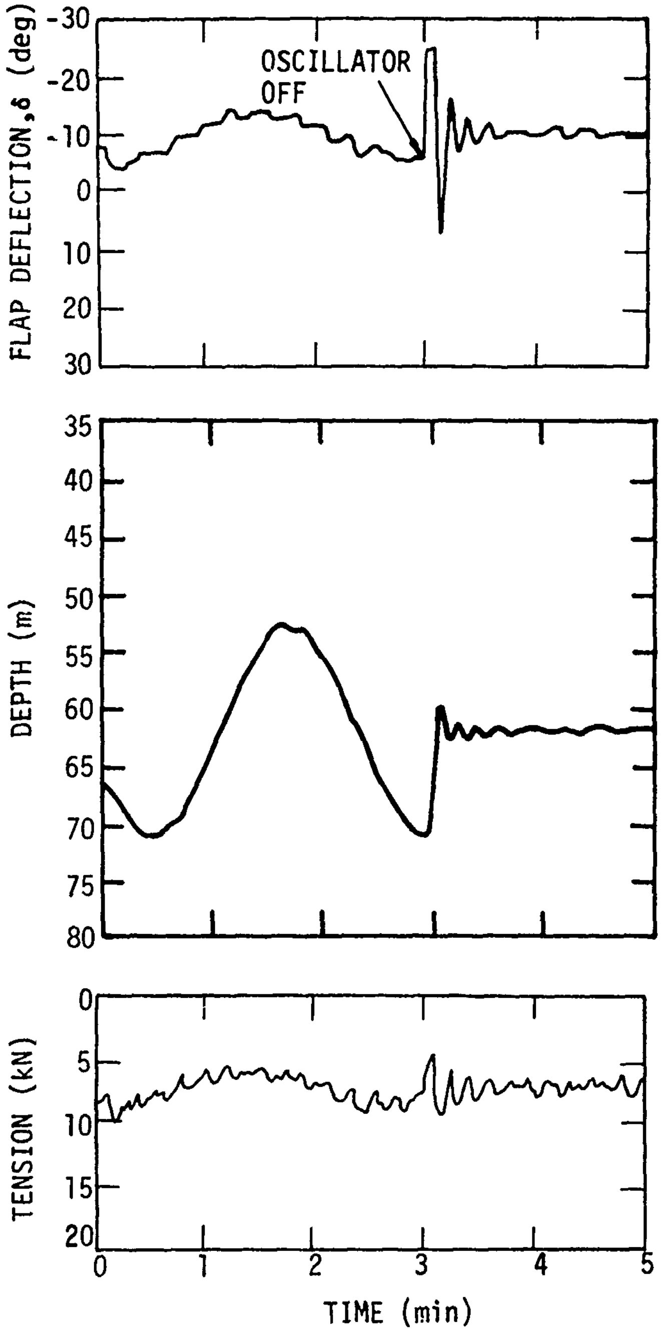


Figure 14b - Frequency, 0.0067 Hertz; Amplitude, Half Full (Run 26)

Figure 14 (Continued)

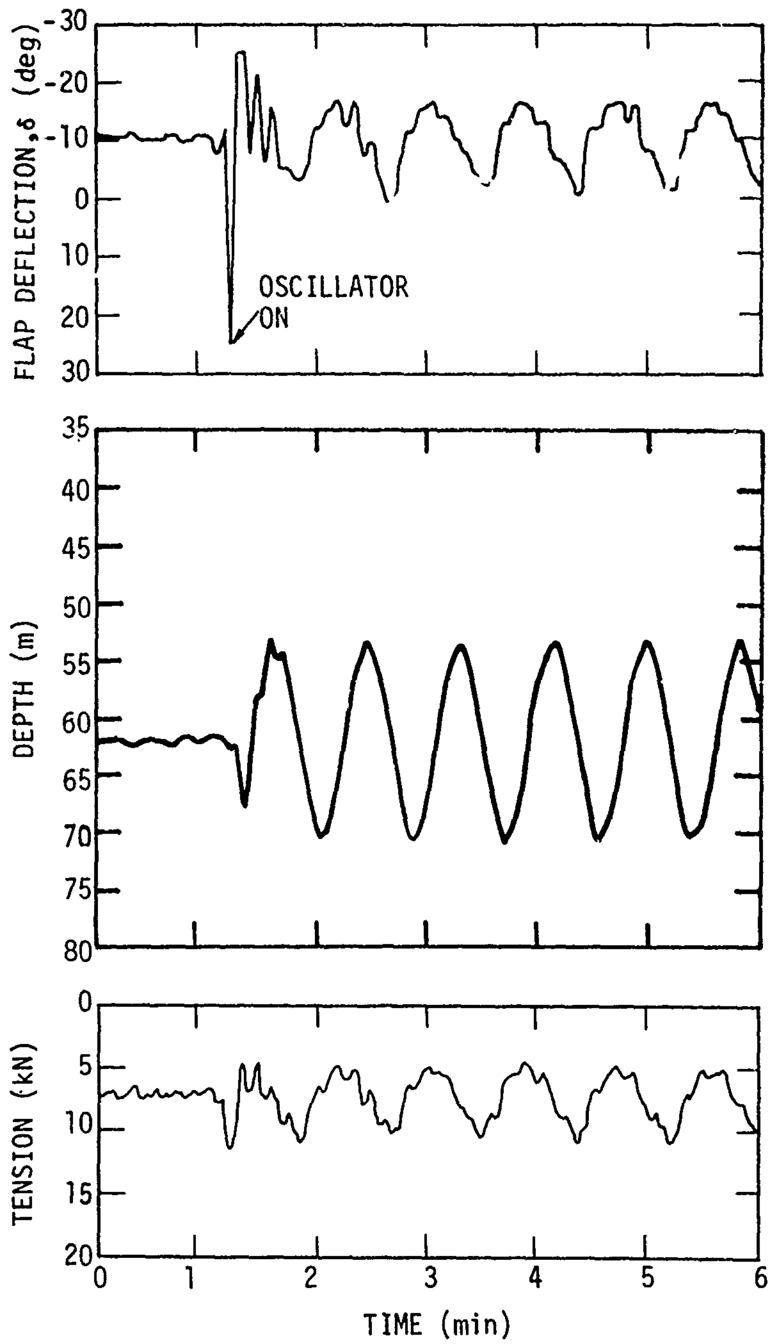


Figure 14c - Frequency, 0.0200 Hertz;
Amplitude, Half Full (Run 22)

Figure 15 - Depressor Response at 10 Knots to Various Sine Wave Control Inputs (Wetted Towcable Length, 115 m; Depth Set, 60 m)

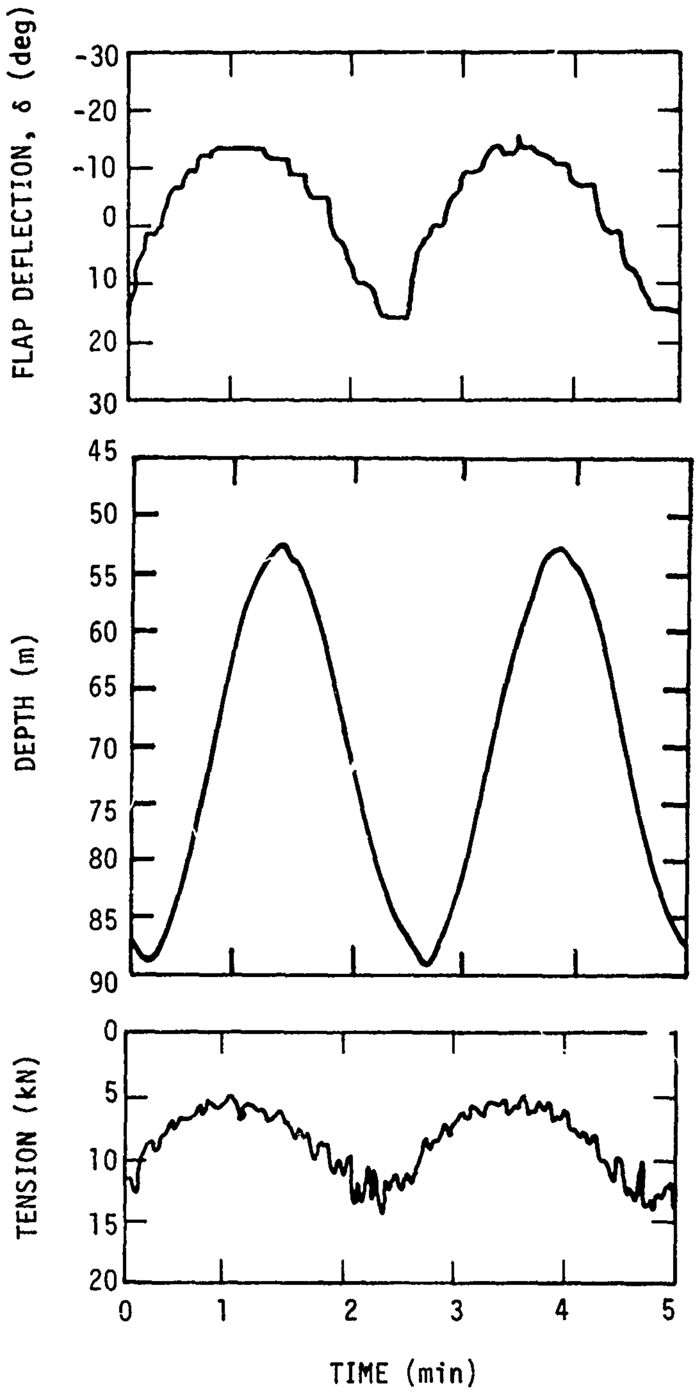


Figure 15a - Frequency, 0.0067 Hertz: Amplitude, Full (Run 29)

Figure 15 (Continued)

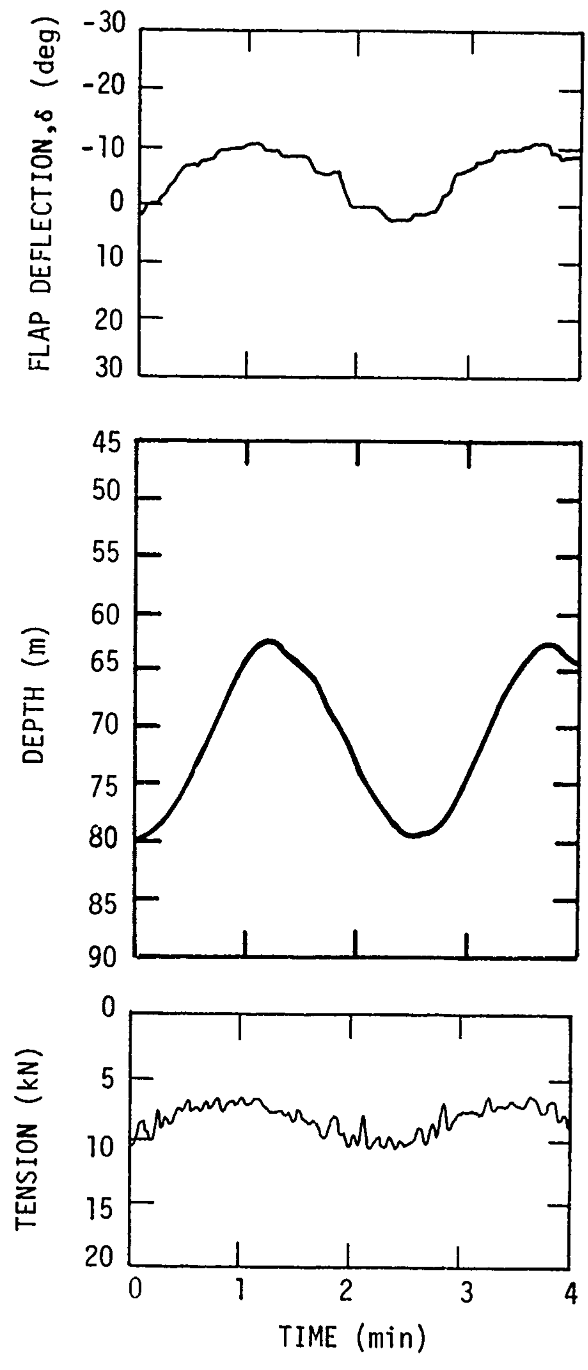


Figure 15b - Frequency, 0.0067 Hertz;
Amplitude, Half Run (Run 27)

Figure 15 (Continued)

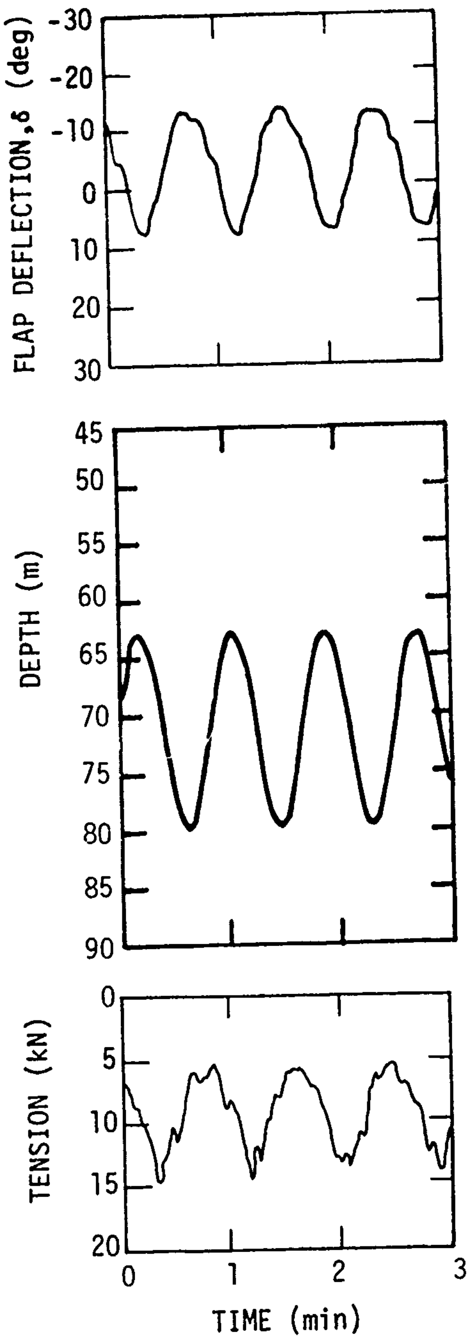


Figure 15c - Frequency, 0.0200 Hertz;
Amplitude, Half Full (Run 23)

was never smooth, responding instead by a series of steps. This undoubtly degraded the towing beh... Also, the relatively low flap gain value of 6.6 deg/m necessary to maintain depressor stability at low coefficients of tension compromises the depth keeping performance at the higher coefficients of tension where the depressor should usually operate.

For all cable lengths and depths investigated, the maximum specified cyclic depth amplitude was achieved at an oscillator amplitude of approximately one-half maximum. At this oscillator amplitude, the depth response was, in all cases, very close to the sine wave control input. The depth profile shaped did tend to deteriorate somewhat with the shorter towline length. This result may have been influenced by increased coupling with the ship motions and by the magnitude of the ship motions, which were greater during this portion of the evaluation.

At maximum oscillator amplitude, the cyclic depth response exceeded the maximum specified depth response by a factor of approximately two. Even at these large amplitudes, the depth profile shape was quite good except for two notable exceptions: the first case occurred during Run 16 (Figure 12d), when the flap fully deflected during the deeper depth portion of the cycle. This resulted in a sharp peak in the depth profile. The second exception occurred during Run 30 (Figure 14a), when the flap was operating in a region corresponding to a low coefficient of tension. At this low tension condition, the depressor transient response apparently was very lightly damped, which resulted in a secondary oscillation superimposed on the primary depth profile. This resulted because depth response is quite sensitive to changes in flap delfection at the lower limit of depressor tension, and unless the flap operates in a smooth manner, depressor motions will be aggravated. As noted earlier, the flap response was less than ideal; the flap often responded in steps of roughly 3 to 4 deg increments.

A high-frequency (0.20 Hz) cyclic depth profile is shown in Figure 13b. For this case the oscillator amplitude was set at approximately one-third maximum. The resulting depth variation was $\pm$ 400 mm. Since to achieve this motion, the flap deflected over most of its range, it is doubtful that a much larger depth profile can be achieved at this frequency.

The transient response of the depressor after turning off the oscillator is shown in several of the recorder traces of Figures 12 through 14. The transient response traces indicate that the depressor has good vertical plane damping, although

damping does decrease somewhat at the lower coefficients of tension. Again, these results probably are adversely affected by the less than ideal control flap response.

Following the evaluation, an attempt was made to improve flap response (Figure 16). Figure 16a shows the flap response as measured in the laboratory prior to any adjustments to the electronics. The response after adjustments were made is shown in Figure 16b. The adjustments consisted of reducing the servo amplifier gain and increasing the input current from 1.3 A to 1.6 A. These adjustments reduced the steps in the flap response from approximately 4 deg to a value somewhat less than 2 deg.

CONCLUSIONS AND RECOMMENDATIONS

The following is concluded:

1. Based on limited evaluation data, the depressor will meet or exceed all performance specifications except at the higher cyclic frequencies (near 0.2 Hz), where the magnitude of the depth excursion is substantially attenuated.

2. Although not necessarily recommended, a cycle amplitude, at lower frequenies, which exceeds the specified value by a factor of two is achievable.

3. The control response is not ideal. Some reworking of the control electronics to improve response probably would improve the overall towing performance of the depressor.

4. Depressor dynamic stability is not excessive at coefficients of tension C_T below 0.6. This situation is aggravated by the lack of a smooth control response. Consequently if the depressor is operated at the lower coefficients of tension, depth excursions will increase. However, unless a very shallow towing depth is required, operation of the depressor in this tension region normally should not be required.

5. The design towcable breaking strength factor of safety is marginal. It will be adequate only if the towcable is properly maintained and the remote sensor cable drag does not cause undue localized stresses.

The following is recommended:

1. Operate the depressor at the highest coefficient of tension condition possible consistent with achieving the required magnitude of cyclic depth control. This will minimize the variations in the relative vertical separations of the remote sensors during cycle excursions (Appendix A). This also will operate the depressor in the region of greatest stability.

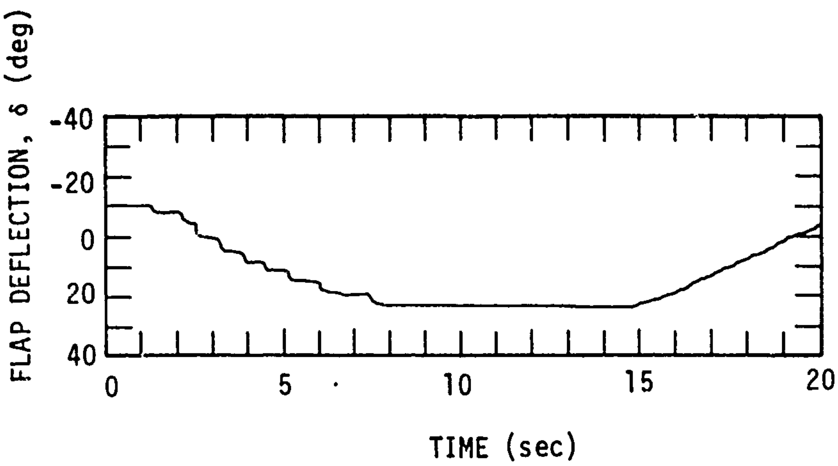


Figure 16a - Before Adjustments to Electronics

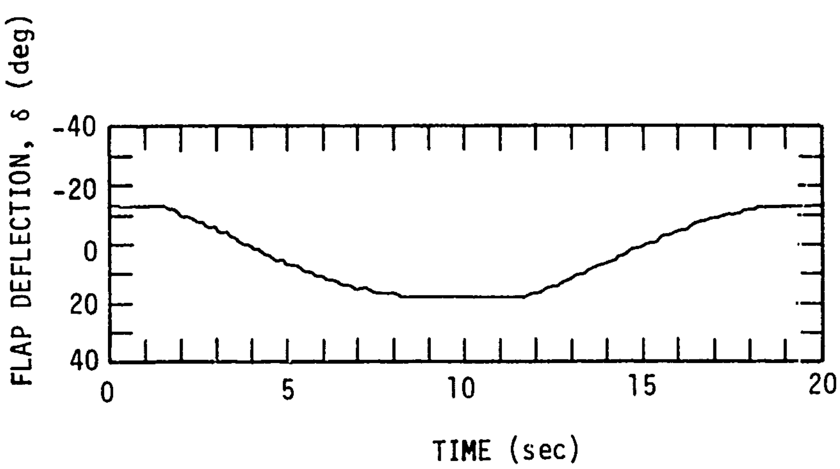


Figure 16b - After Adjustments to Electronics

Figure 16 - Control Flap Response to Sine Wave Input (Bench Test) Following Sea Evaluation

2. Investigate improvements to the control electronics.

3. To decrease the chances of towcable breakage, meticulously inspect and maintain the towcable. Cable maintenance guidelines are discussed in Appendix B. To further reduce the risks, consider a reduction in the operational towing speed from 10 knots to 8 knots. This will increase the static tension factor of safety from 2.7 to 4.2. Lower speed also will proportionately decrease the dynamic towing loads.

APPENDIX A

PREDICTED HYDRODYNAMIC PERFORMANCE CURVES

The forces produced by the depressor along with cable parameters provide the necessary input for calculating the configurations and forces of the towcable. The depressor tension characteristics measured during the basin experiment are presented in Figure 9. In addition, the towcable angle at the depressor must be known. Towcable angle has not been measured. However, an estimate based on data from another depressor of similar design is presented in Figure 17.

Predicted depressor depth as a function of depressor coefficient of tension is presented in Figure 18 for various towcable wetted lengths and towing speeds; the predictions assume that the remote sensors are positioned along the towcable at locations 10 and 20 m above the depressor. Figure 18 allows selection of a towcable length to satisfy a given depth requirement. It also provides an indication of the tension variation (flap angle variation) required to achieve a desired depth profile.

Data from the at-sea evaluation also are plotted in Figure 18 for comparison with the predictions. For the cable lengths and speeds evaluated, the measured depth values are consistently deeper than the predicted values by 5 to 10 m. This difference is possibly related to the previously discussed discrepancy between the set depth and measured depth; or it may be the result of predictive errors.

The accuracy of using Figure 18 to predict cyclic depth variation will degrade as oscillation frequency increases. An indication of this degradation is shown in Figure 19. Dynamic data from the at-sea evaluation in conjunction with the static depth predictions of Figure 18 were used to obtain the cyclic depth attenuation factor of Figure 19. The attenuation factor k is define to be

$$K \equiv \frac{A_1}{A_o} \tag{4}$$

where A_1 is the measured dynamic depth variation corresponding to various cycle frequencies, towcable lengths, and flap deflection ranges; and

A_o is the static depth variation for the same towcable lengths and flap deflection ranges (predicted using Figure 18)

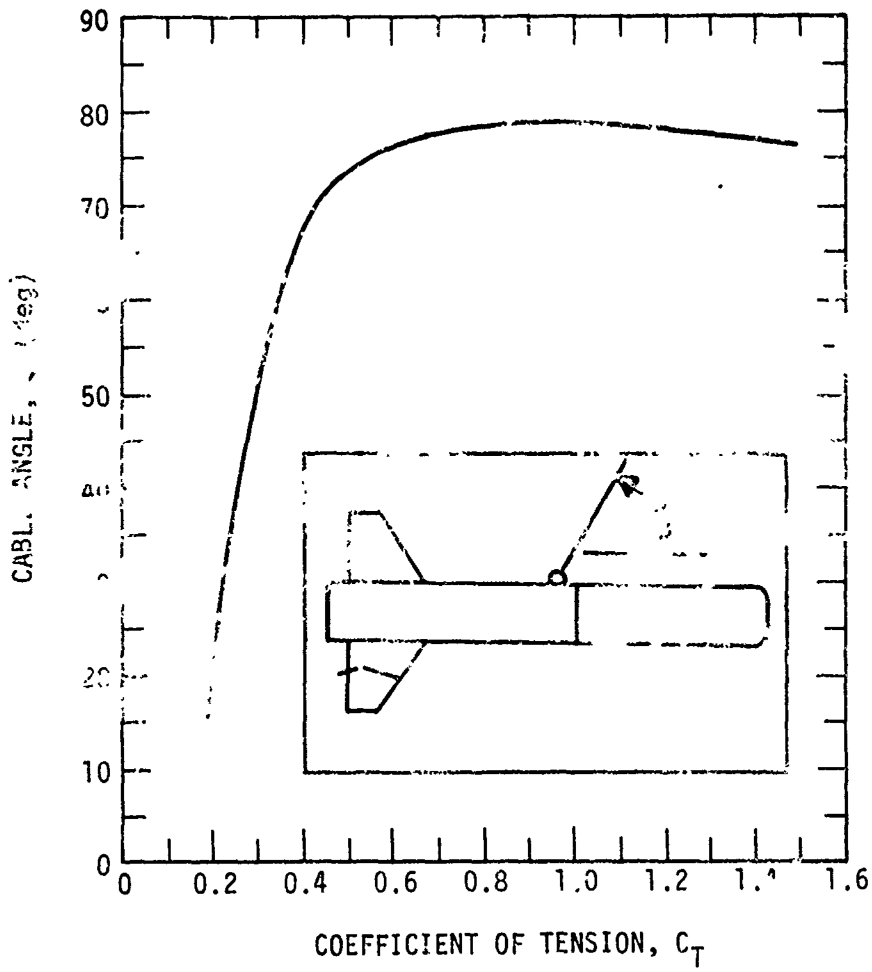
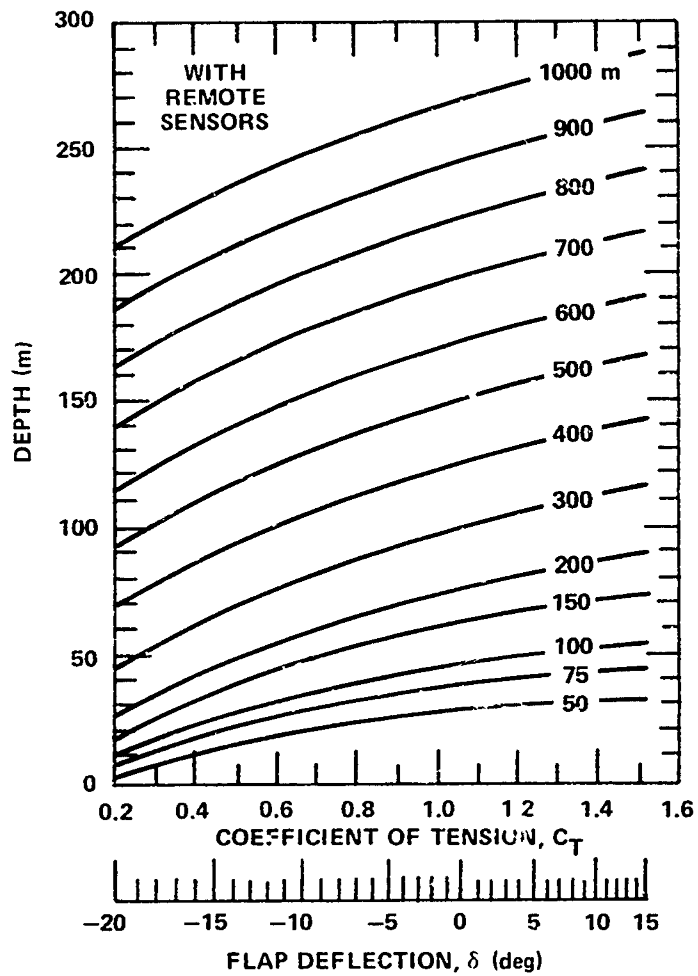


Figure 17 - Estimated Cable Angle at Depressor as a Function of Depressor Coefficient of Tension

Figure 18 - Predicted Depth as a Function of Depressor Coefficient of Tension for Various Wetted Towcable Lengths and Speeds



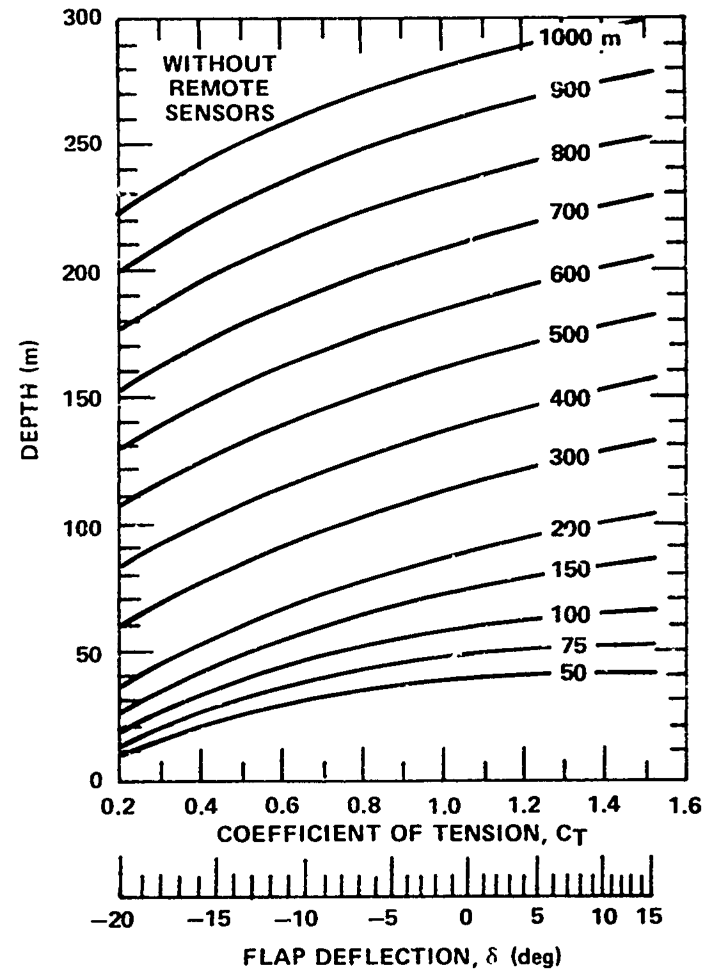


Figure 18a - 4 Knots

Figure 18 (Continued)

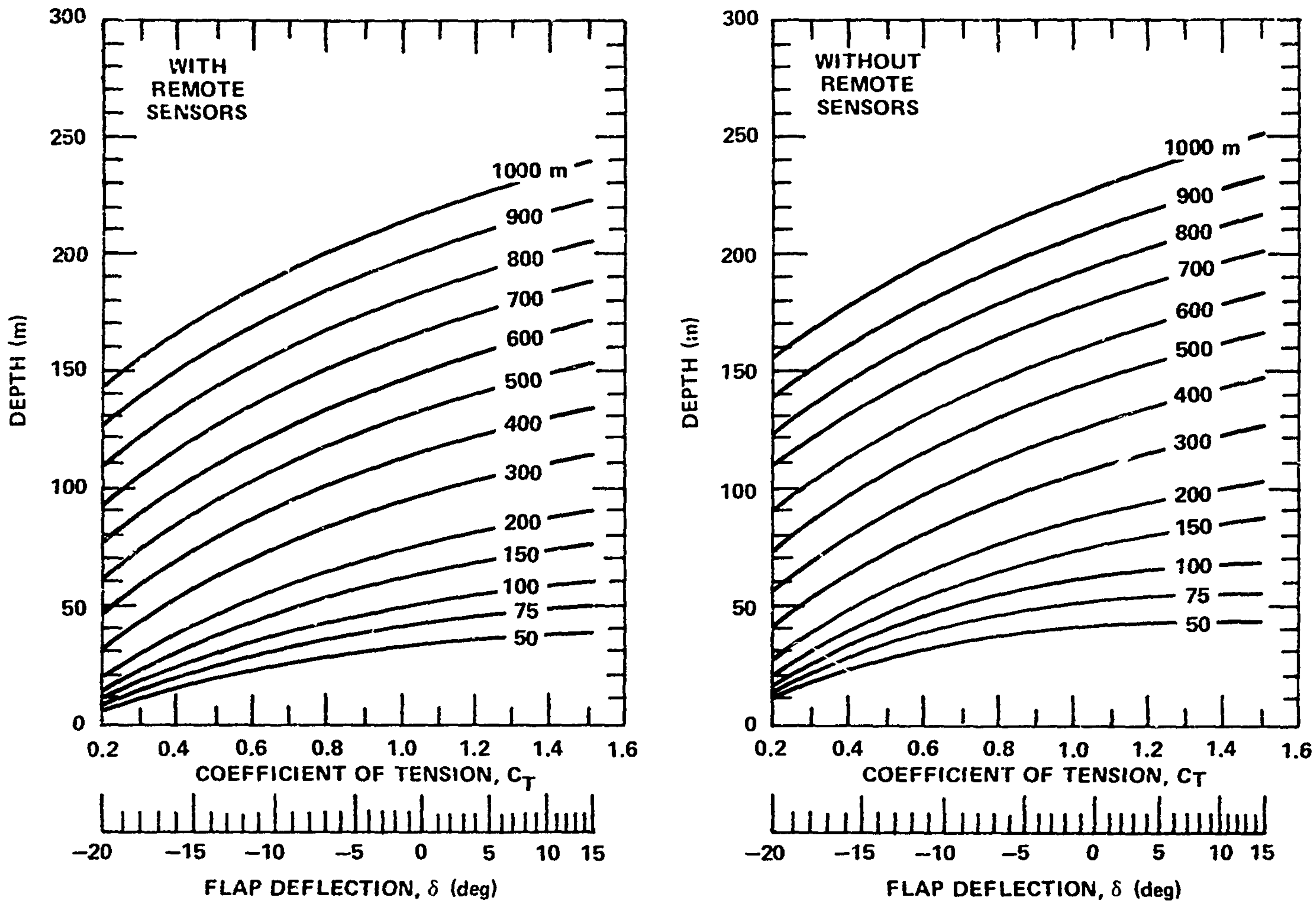
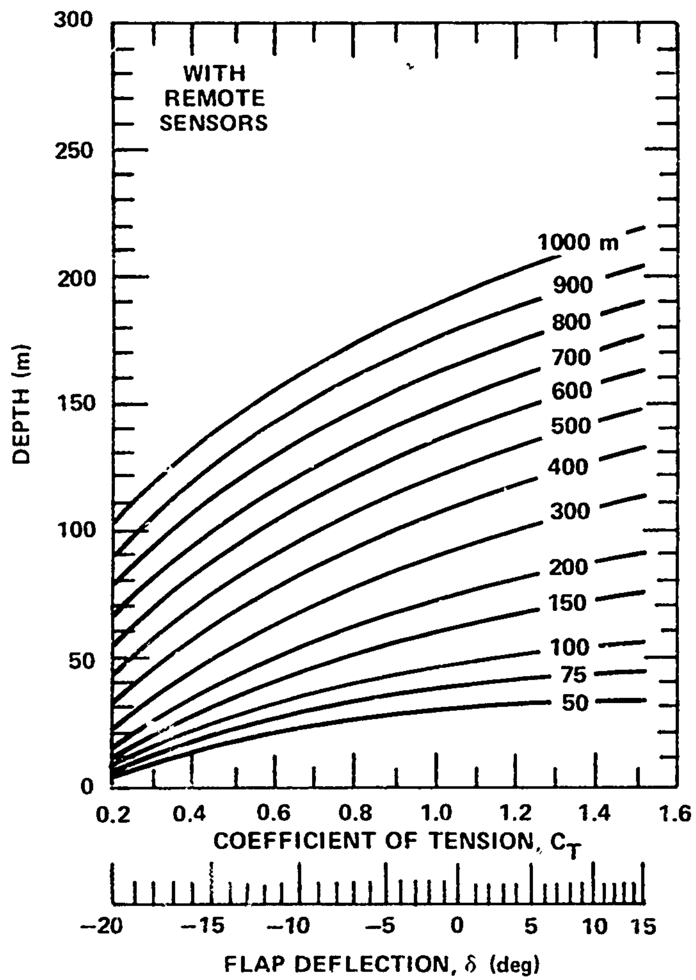


Figure 18b - 6 Knots

Figure 18 (Continued)



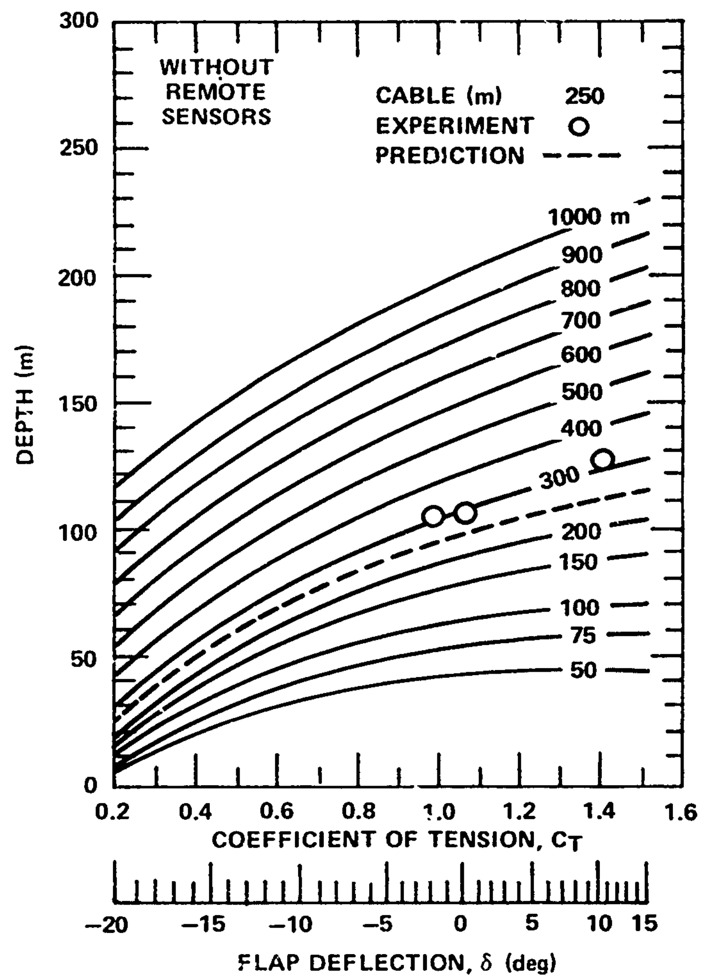


Figure 18c - 8 Knots

Figure 18 (Continued)

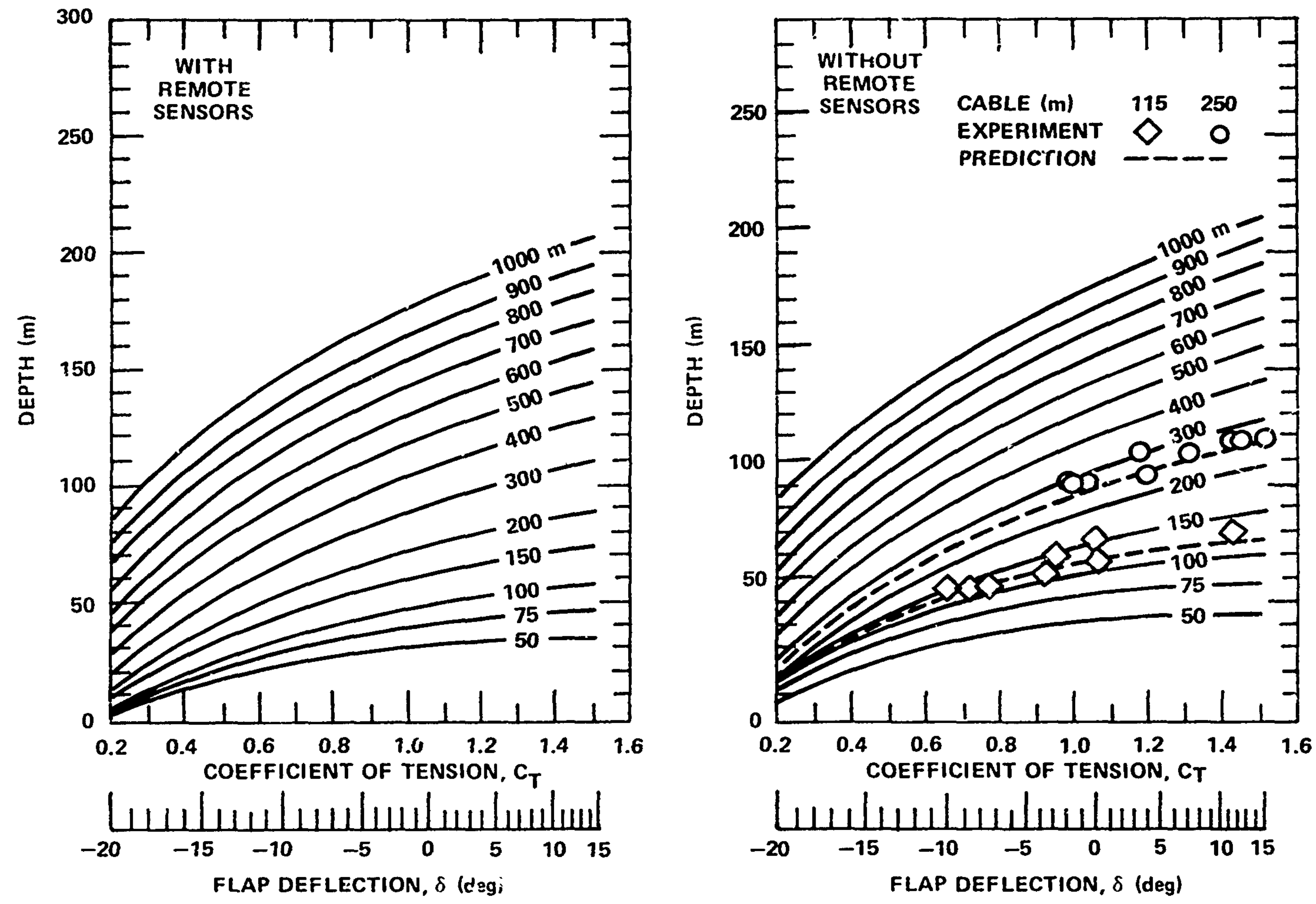


Figure 18d - 10 Knots

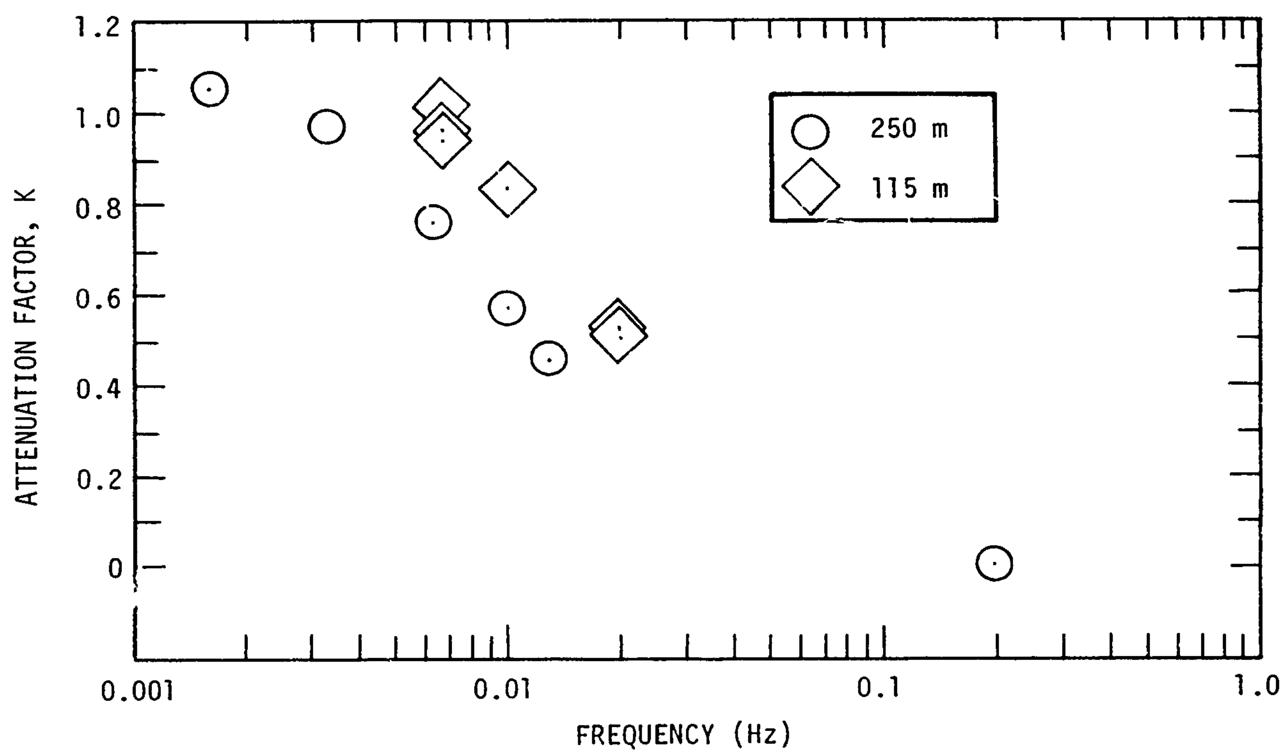


Figure 19 - Cyclic Depth Attenuation Factor as A Function of Cycle Frequency for Two Wetted Towcable Lengths

The predicted changes in the vertical separations of the remote sensors relative to the depressor corresponding to changes in depressor coefficient of tension are shown in Figure 20. The predictions assume that the remote sensors are 10 and 20 m above the depressor when the depressor is operating at a tension coefficient C_T of 1.5. This figure indicates the importance of operating as close as possible to the maximum coefficient of tension to minimize relative height variations during cyclic control.

Predicted towing tension as a function of wetted cable length is shown in Figure 21 for various speeds and depressor tension conditions. The sharp increases in tension near the depressor indicated on some of the plots result from the drag of the remote sensor cables. At-sea data are not compared to the predictions in Figure 21 since the available tension results apparently were strongly affected by the depressor depth cycling. However, inspection of the data indicates that the predictions are at least nominally correct and adequate for the purpose.

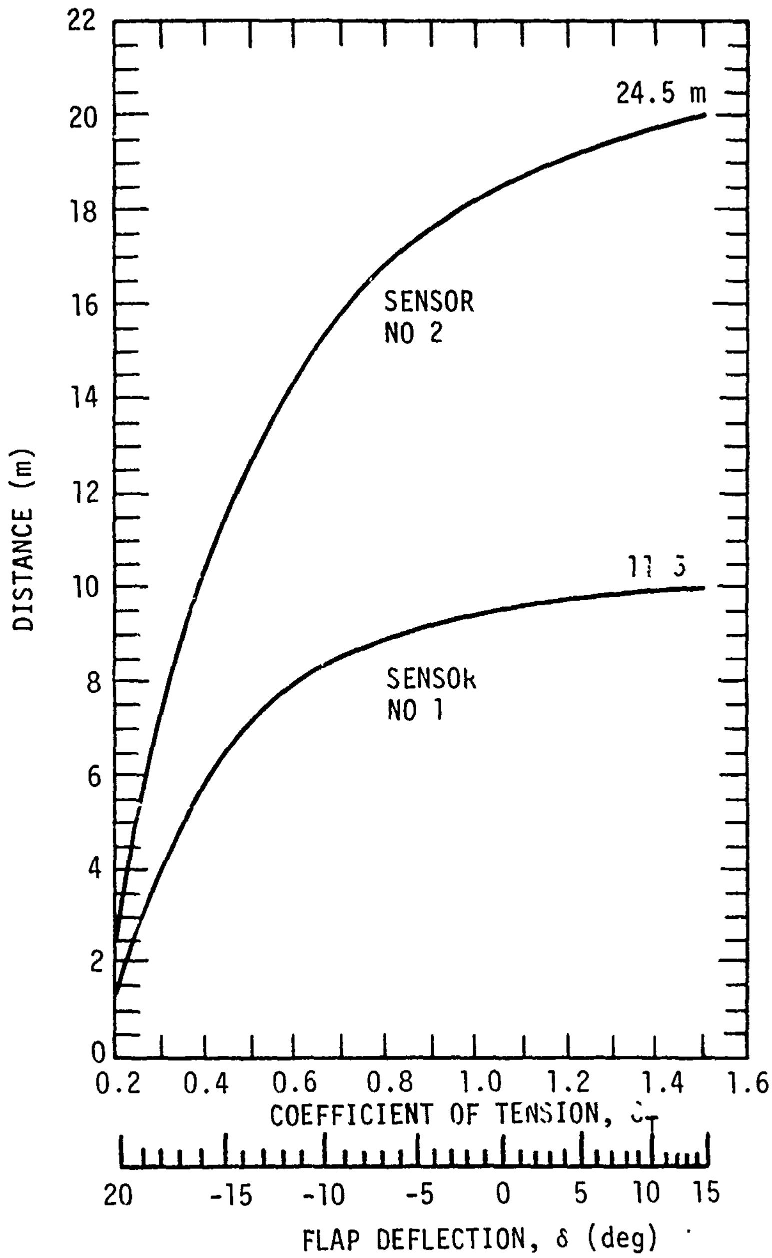


Figure 20 - Predicted Remote Sensor Distance Above Depressor as a Function of Depressor Coefficient of Tension for Sensors at Two Locations Along the Towcable

Figure 21 - Predicted Towing Tension as a Function of Wetted Towcable Length for Various Depressor Coefficients of Tension and Speeds

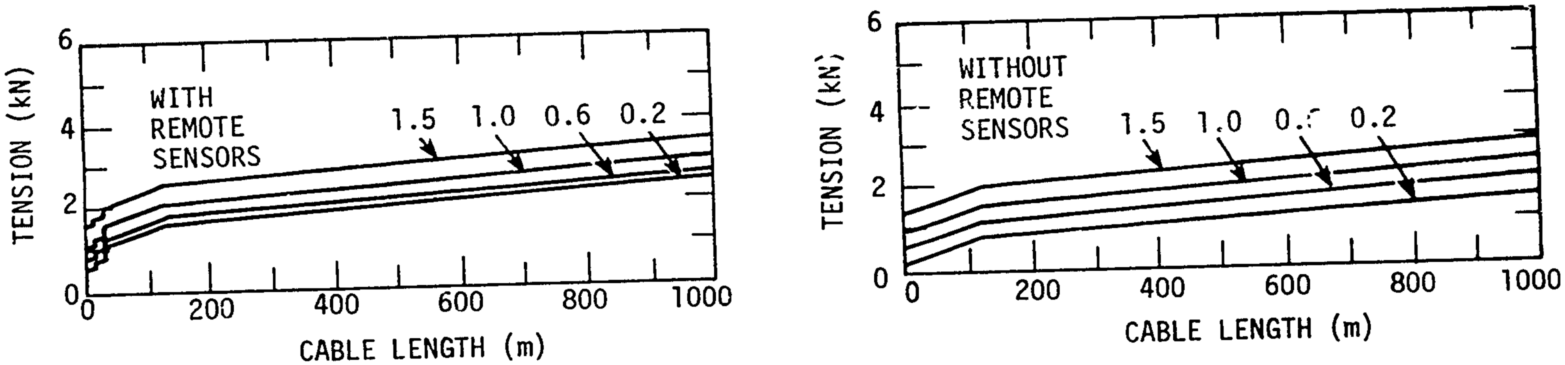


Figure 21a - 4 Knots

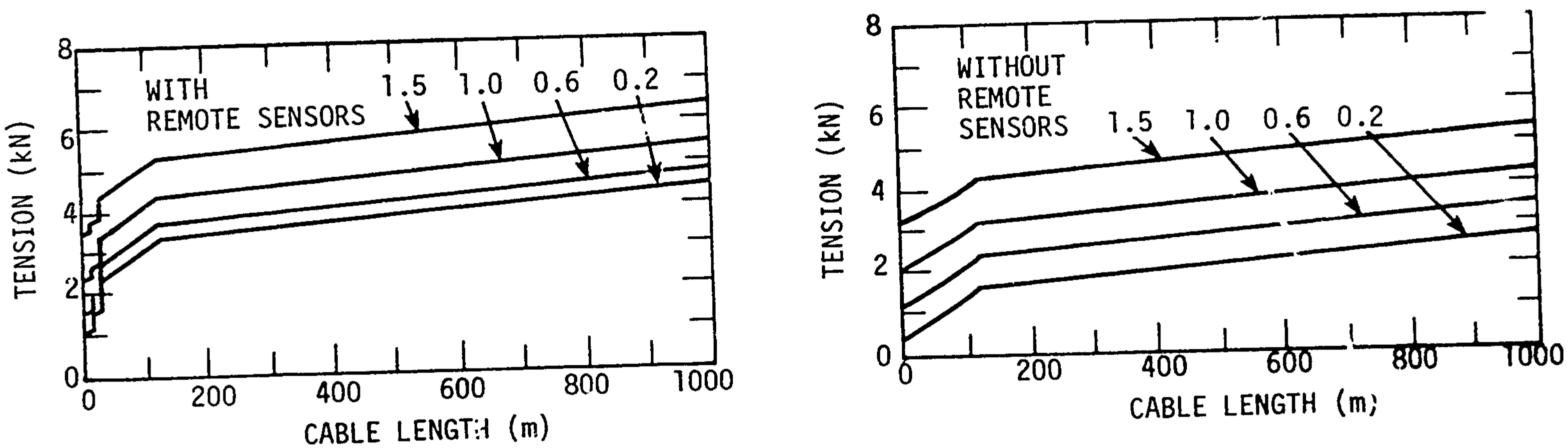
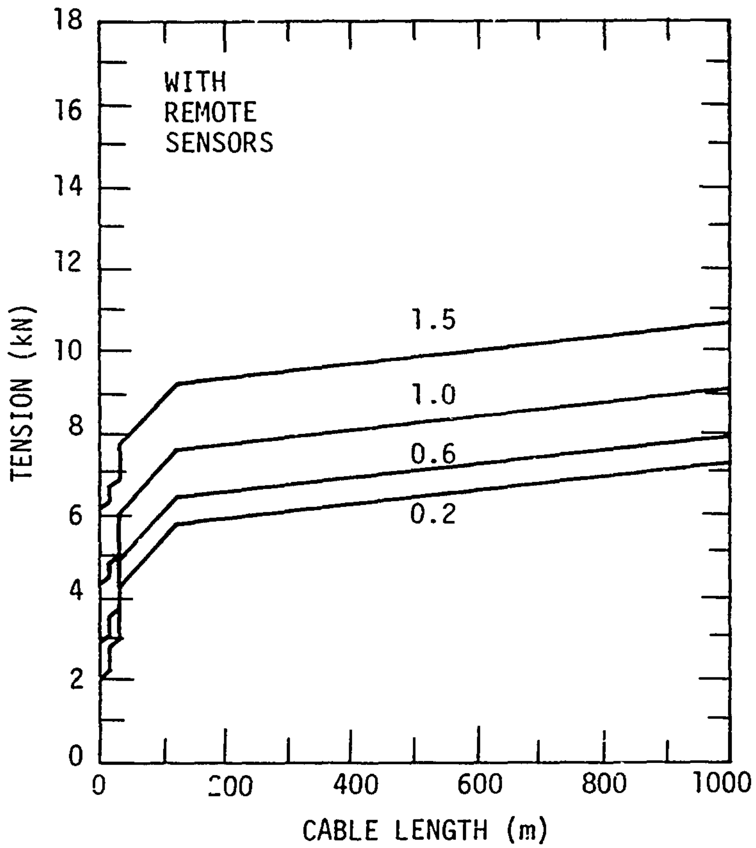


Figure 21b - 6 Knots

Figure 21 (Continued)



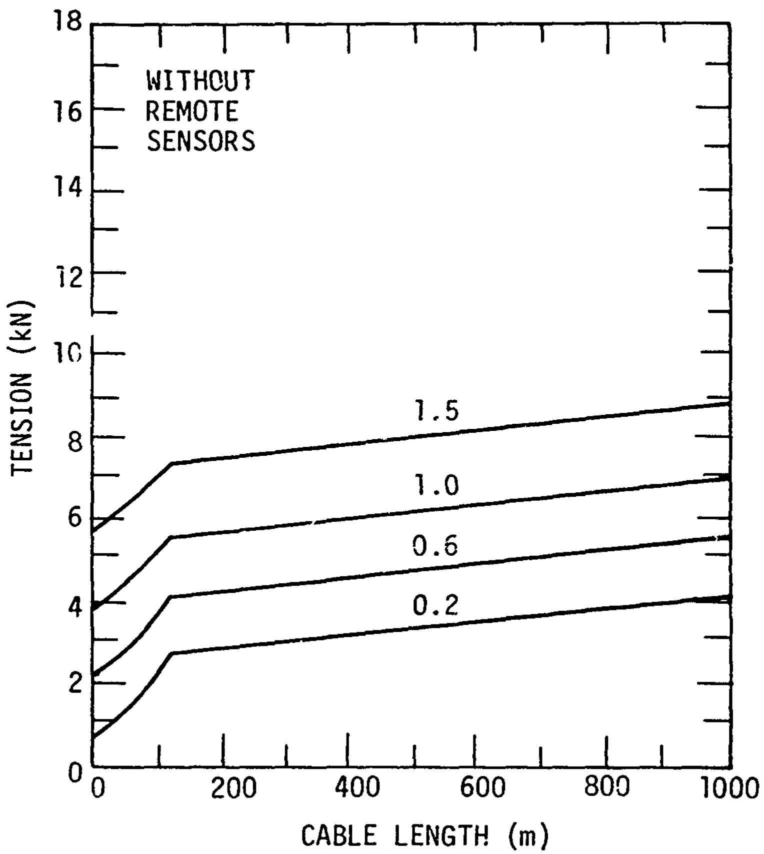


Figure 21c - 8 Knots

Figure 21 (Continued)

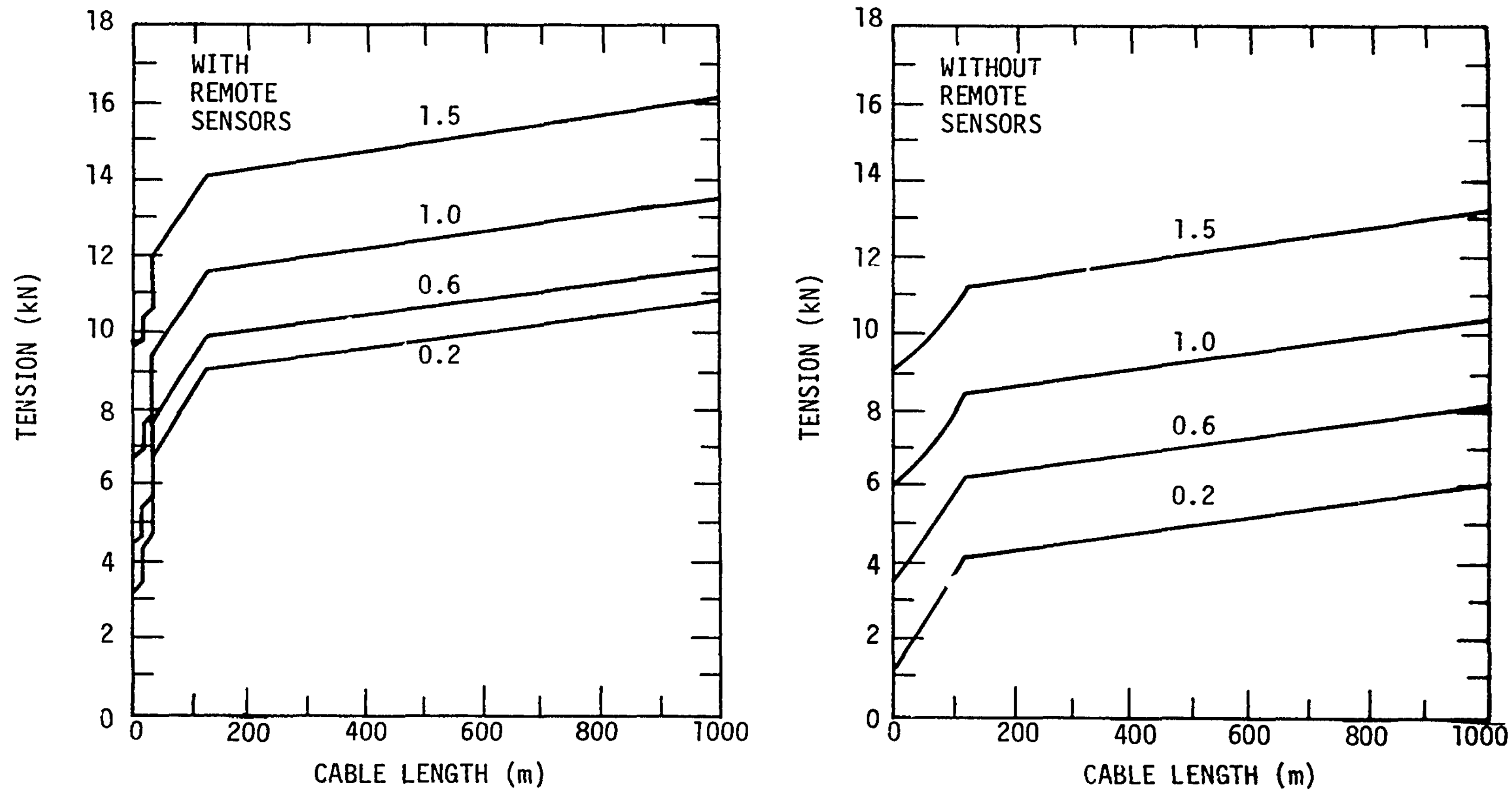


Figure 21d - 10 Knots

APPENDIX B

MAINTENANCE AND OPERATION GUIDELINES

The following sections provide maintenance, inspection, and operating guidelines for the CDT depressor equipment.

EQUIPMENT INSPECTION AND MAINTENANCE

The depressor should be inspected visually after retrieval and prior to launching to ensure that there is no damage. Some hairline cracks may appear at the wing/fuselage junction. This indicates that the surface paint has cracked due to flexure of the wings during towing and is of little concern. Paint also may chip away at various surface locations on the depressor. This is of no real concern unless it occurs on the convex surface of the wing, particularly near the leading edge. If large areas of paint chip away on this surface, hydrodynamic performance, primarily lateral trim, can be adversely affected. The wing surface should be kept relatively smooth by sanding and refinishing as required.

Screws and bolts should be checked frequently to ensure that they are tight. If any screws have loosened, they should be cleaned, coated with "lock tite," and reinserted (self-locking screws can be used in lieu of lock tite). The roll-pin which secures the roll-trim pendulum also should be checked periodically. If the roll-pin has worked loose, it should be replaced. Also, the roll-trim tab should be exercised before the depressor is launched to ensure that it pivots freely. If the roll tab is not operating properly, it will adversely affect depressor performance.

Although not necessarily required, all aluminum hardware should be washed with freshwater after daily towing operation to remove salt buildup and to retard corrosion. If the equipment is to be put into storage for an extended period a thorough washing with freshwater is highly recommended.

Whenever a pressure housing is disassembled, the O-ring and O-ring contact surfaces should be cleaned and inspected for nicks; ideally the O-ring should be replaced. O-ring surfaces must be recoated with silicone grease or a similar nonwater-soluable grease during assembly.

Before assembly of underwater connectors, make sure all connector O-rings are in place and in satisfactory condition. Coating these O-rings with grease also is recommended. Otherwise, manufact· rer instructions should be followed.

The towcable armor should be inspected during each retrieval and during launching, particularly at the remote sensor locations, for signs of abrasion and for broken wires. The remote sensors will induce a degree of stress concentration in the towcable and increase susceptibility to local fatigue failure. If more than one or two armor strands are broken at a particular location, the cable should be cutoff at this location and reterminated. To decrease the likelihood of cable fatigue, the remote sensors shoud be shifted to slightly different locations each time they are secured to the towcable. If experience with the system indicates that the cable fatigue at the remote sensor location is a problem, a rubber liner in the brass clamp may reduce this tendency. Otherwise, alternate methods of securing the sensors will have to be examined.

The towcable will begin to show red-colored corrosion as the galvenizing is abraded away. Washing the cable with freshwater during retrieval will help prolong the life. With proper care, the towcable probably can be used for about 500 hours of towing. If the towcable is put into storage for an extended period, it should be thoroughly cleaned of any saltwater deposits. A coating of grease may also help. Recently, Rochester Corporation has begun to manufacture this cable design using Nitronics 50, a material which apparently is not susceptible to corrosion. As a further measure to prolong cable life, the minimum cable bend radius should never be less than 150 mm (12 in.).

Some ribbon-fairing normally will be stripped from the cable by sheaves, etc. during streaming and retrieval. Approximately 50 percent of the fairing can be lost before performance of the fairing is appreciably degraded.

CONTROL ELECTRONICS OPERATION

To operate the control electronics, preset the following switches and control on the shipboard instrument package prior to connection to the ac line.

Control Unit

1. ON-OFF SWITCH - to OFF position
2. RANGE SWITCH - to position 0
3. RANGE VERNIER - to 0050

Kepco Power Supply

1. POWER SWTICH - to OFF position
2. VOLTAGE CONTROL - to maximum counterclockwise position

Function Generator

1. LINE SWITCH - to OFF position
2. DC OFFSET LEVEL - to 0 position
3. FUNCTION SWITCH - to SINE position
4. OUTPUT LEVEL control - to maximum counterclockwise position
5. RANGE SWTICH - to 0.001 position
6. FREQUENCY DIAL - to any setting desired

The following turn-on procedures are recommeded.

1. Make sure all connections between the control unit and the depressor control housing are correct. Refer to DTNSRDC Drawing C-588-2.

2. If the system is being checked out with the towcable in line, make sure the voltage control lead is connected to 5, 6, and 7 of the Kepco rear terminal board as shown on C-588-1.

CAUTION

The voltage control lead connected to 5, 6, and 7 of the terminal board at the rear of the Kepco power supply must be disconnected whenever the system is operated without the towcable. Operating the control electronics out of water for an extended period (45 min or more) will cause overheating of the depressor control housing if the control flap remains stationary.

Note: When the towcable is <u>not</u> used in checking the system and the servomotor is running, the Kepco power supply voltage will increase by 30 V to 60 V at the instrument housing in the depressor which may cause destruction of the two positive 12 V regulators in the housing if the voltage lead is not disconnected from the terminal board as mentioned in the above CAUTION.

3. Check to see that the ac plug, dc power supply cable (P.S.) and deck cable (from the towcable) are properly connected to the rear of the control unit. A readout of the depressor stabilizer angle, depth and delta depth may be obtained by interconnecting between the control unit and a voltmeter or preferrably a multi-channel strip chart recorder.

4. Connect the three power plugs from the control unit, Kepco power supply, and the function generator to a 110 V, 60 Hz power source.

5. Turn the ON-OFF switch of the control unit to ON.

6. Turn on the power switch of the Kepco power supply and adjust the voltage control to obtain 1.3 to 1.6 A on the ammeter.

7. Turn the LINE switch of the function generator on ON.

The system is now active and can be operationally checked on deck as follows:

1. Adjust the RANGE VERNIER potentiometer of the control unit from 0500 towards a 000 reading (counterclockwise rotation) and at some point near zero the flap should start to move. When the flap moves to a new position observe the current reading of the Kepco power supply; it should increase towards 1.5 to 1.7 A when the flap is actually moving and may drop to 0.6 A when the flap is at rest but not at a limit position.

2. Adjust the OUTPUL LEVEL control on the function generator to cause the flap to oscillate synchronously with the frequency setting of the generator.

3. The measurement of flap angle, depth, and delta depth may be obtained using a strip-chart recorder and setting the sensitivity of the recorder to obtain the cal-step readings listed in Table 4. The calibration sequence is ZERO CHECK (ZC), CAL1 (C1), and CAL2 (C2). The electrical calibration steps are generated by momentary depression of the CAL START pushbutton on the control unit.

TOWING OPERATION

The amount of towcable length will depend upon the maximum desired towing depth and to a lesser extent on the towing speed. For best dynamic performance, the depressor should be operated at near maximum coefficient of tension (C_T max = 1.5). Also at high tension coefficients the vertical separations of the remote sensors will remain more nearly constant during cyclic depth control (Figure 10). The proper operating condition can be achieved using the following procedure.

TABLE 4 - CONTROL CALIBRATION

Function	ZC	C1	C2
Flap Deflection, deg	0	+15	-15
Depth, m	0	101.6	203.2
Delta Depth*, m	0	101.6	203.2

*Delta depth sensitivity is a factor of 10 greater then depth.

1. Using Figures 18 and 19, estimate the length of towcable required to obtain the depth and the desired cyclic depth variation. A tension coefficient C_T near 1.5 should be selected for the deepest portion of the depth cycle for the reasons discussed above.

2. Launch the depressor and begin paying out towcable.

CAUTION

If the towcable is on the winch at little or no tension, ship speed should be maintained at 3 knots or less during launching operations to prevent the outer towcable lays from burying themselves under subsequent lays.

The towcable is marked at intervals using patches of ribbon fairing to provide a measure of the amount of cable payed out. The marking scheme is listed in Table 5. A metering device, such as a metering streaming sheave, also can be used to determine cable payout.

3. After paying out the desired cable length, secure the towcable to the ship towpoint. Always install a tension dynometer to monitor towing tension.

4. Set desired towing depth and commerce towing at operational speed.

CAUTION

Do not allow the towcable tension to exceed 18 kN (4000 lb). If sea conditions or other factors cause tension surges to approach this value, decrease towing speed. Also, if median tension vary greatly from those predicted in Figure 21 the depressor should be retrieved and inspected for damage.

5. Observe towing depth and fine tune the depth setting, as required, using the depth readout (ideally the CTD depth readout). To change the depth, dial in a new setting and allow sufficient time for depressor depth transients to settle before making any further adjustments.

TABLE 5 - TOWCABLE CALIBRATION

Distance* (meters)	Cable Marking
0	Towstaff
25	One Bare Spot, 150 mm long
50	Two Bare Spots, each 150 mm long
75	Three Bare Spots, each 150 mm long
100	Four Bare Spots, each 150 mm long
120	End of Ribbon Faired Section
150	One Patch, three ribbons
200	Two Patches, six ribbons each
250	One Patch, three ribbons
300	Three Patches, six ribbons each
350	One Patch, three ribbons
400	Four Patches, six ribbons each
450	One Patch, three ribbons
500	Five Patches, six ribbons each
550	One Patch, three ribbons
600	One Patch, six ribbons
650	One Patch, three ribbons
700	Two Patches, six ribbons each
750	One Patch, three ribbons
800	Three Patches, six ribbons each
850	One Patch, three ribbons
900	Four Patches, six ribbons each
950	One Patch, three ribbons
1000	Five Patches, six ribbons each

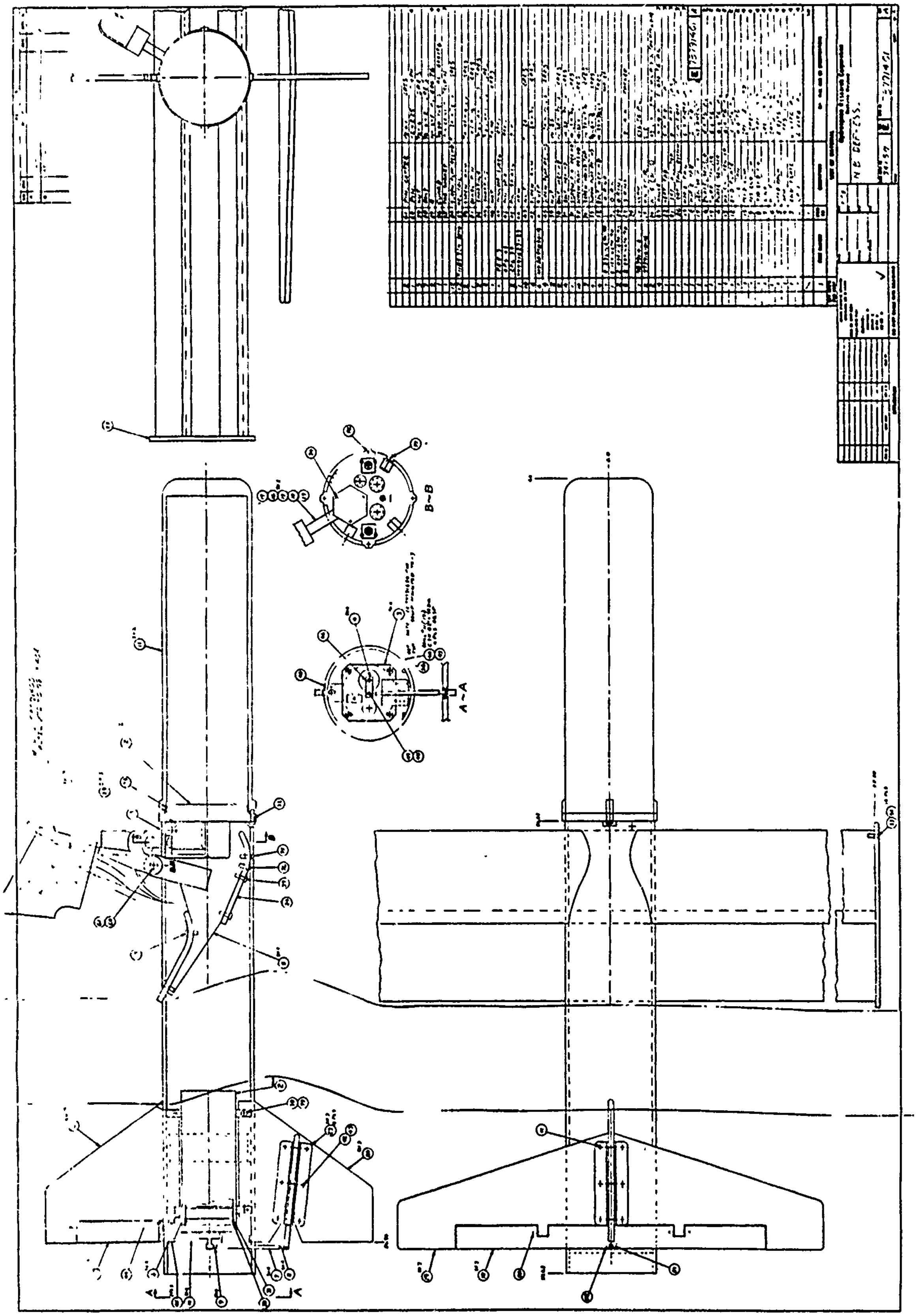
*Ribbon Fairing extends from 0 to 125 m along cable.

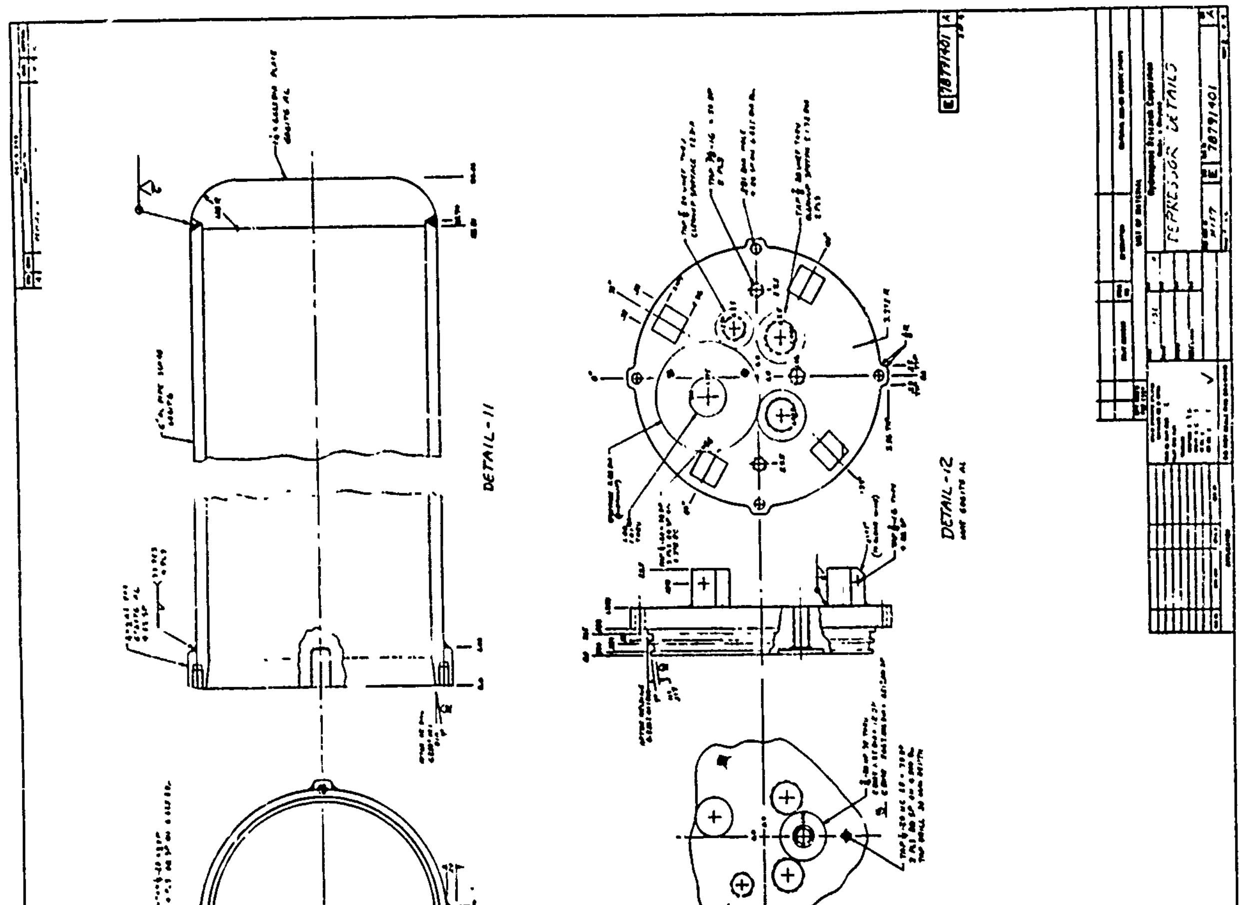
6. Cycle the depressor at the desired frequency and amplitude. If the towcable length is adjusted properly, the control flap will deflect to a maximum dive angle of approximately 15 deg. If the flap dive angle is exceeding this value, towcable length should be increased slightly using Figure 18 as a guide. If, however, the depth cycle does not cause the flap to approach this value, the cable length should be shortened.

Turns, when required, should be made at a gentle rate. Always monitor depth and tension in a turn. As long as depth is maintained and tension does not become excessive, the turn rate can be judged satisfactory. If towing behavior does become erratic, decrease the turn rate and/or the speed.

APPENDIX C

HARDWARE CONSTRUCTION DRAWINGS


B-B
A-A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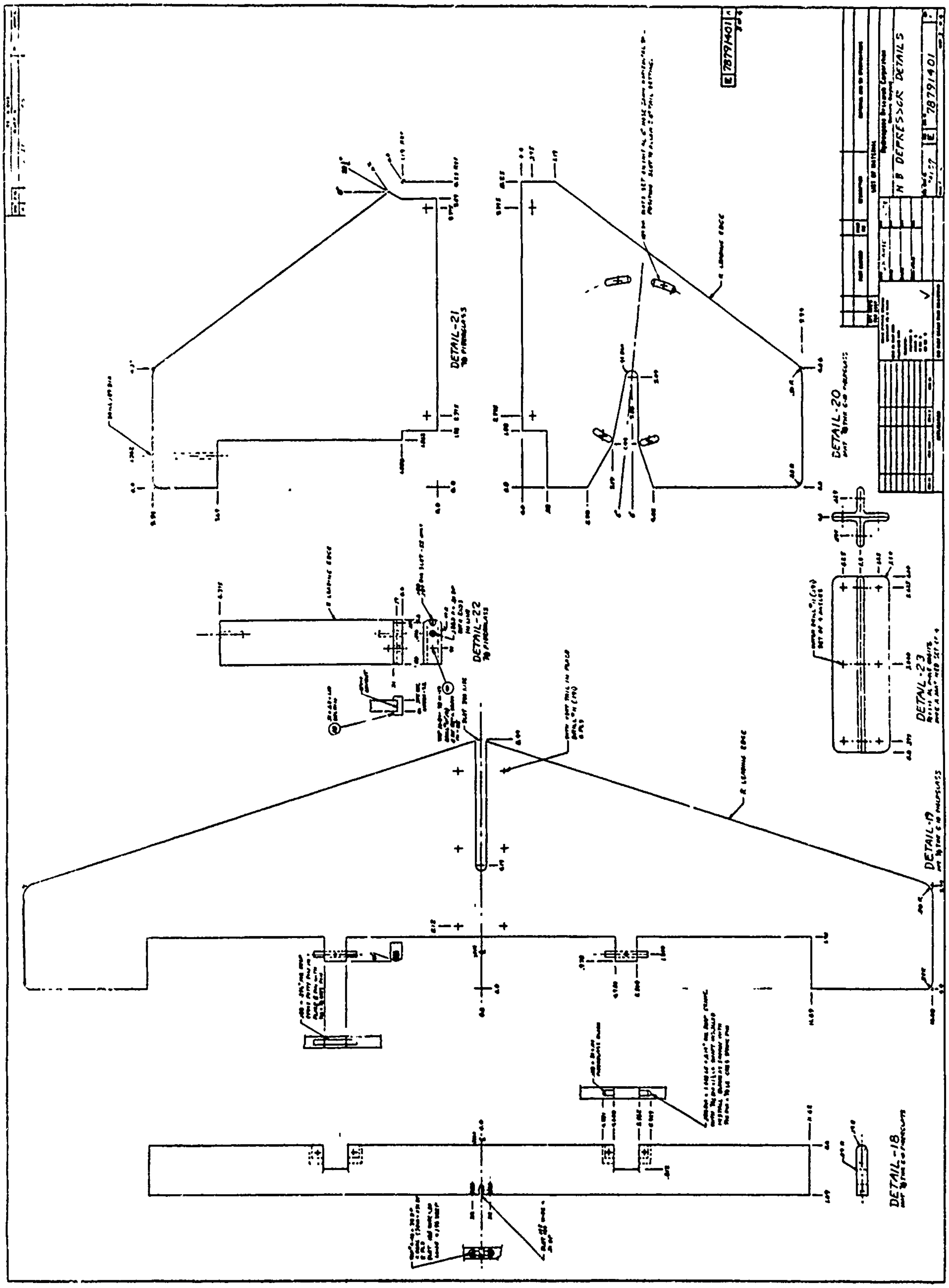
DETAIL-13
DETAIL-14
DETAIL-15
DETAIL-16
-17 ASSY
78791401



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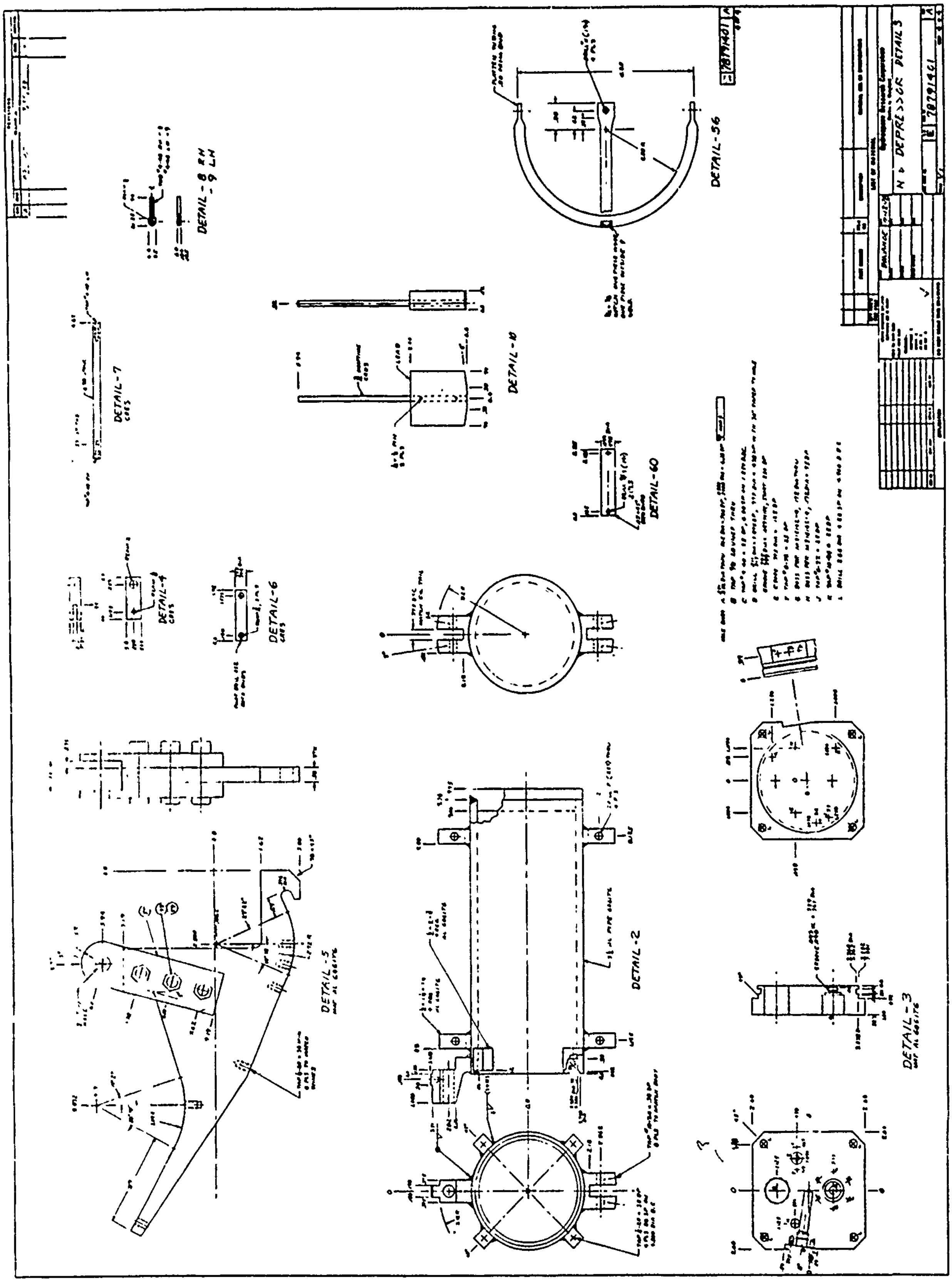
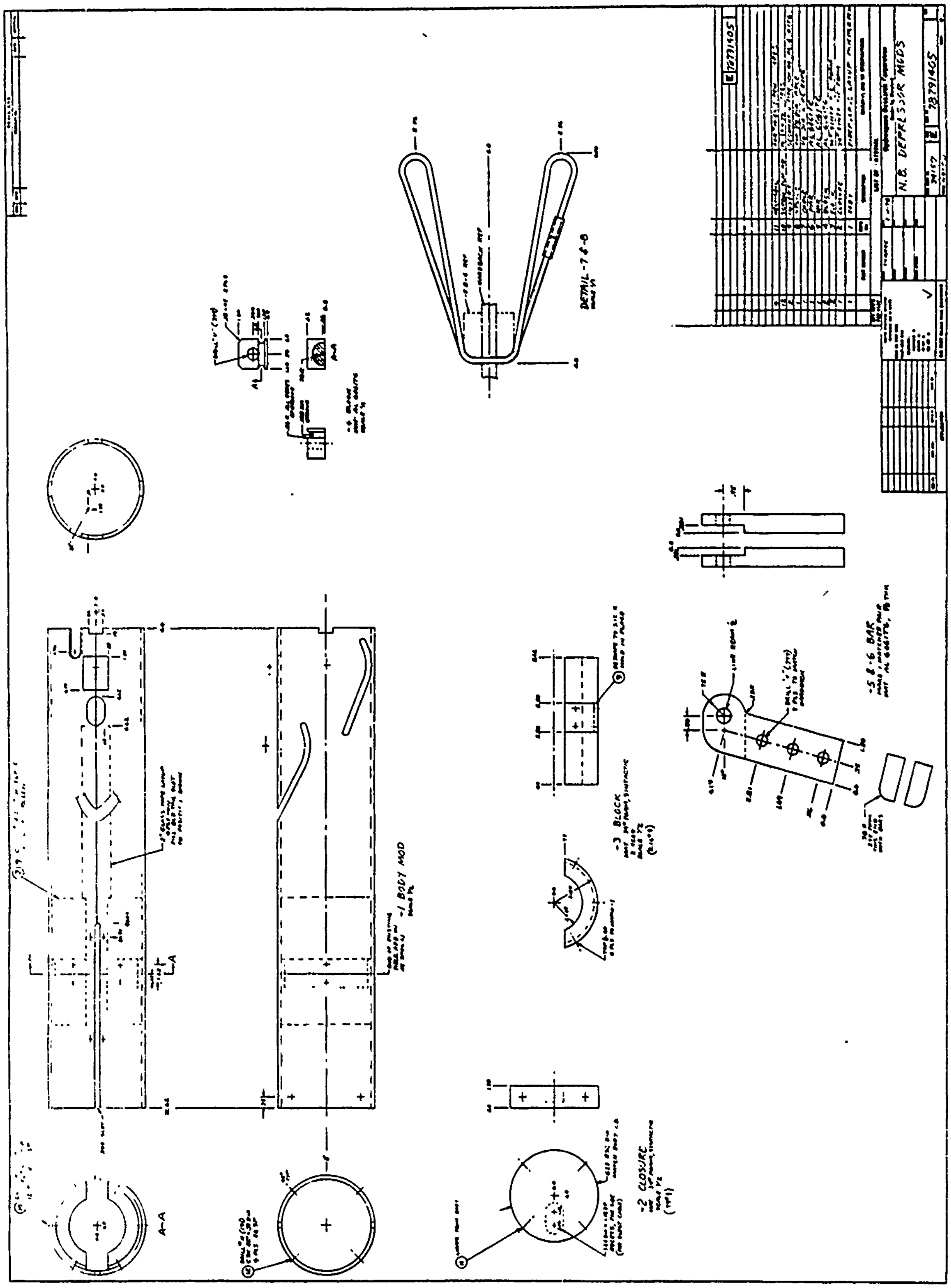
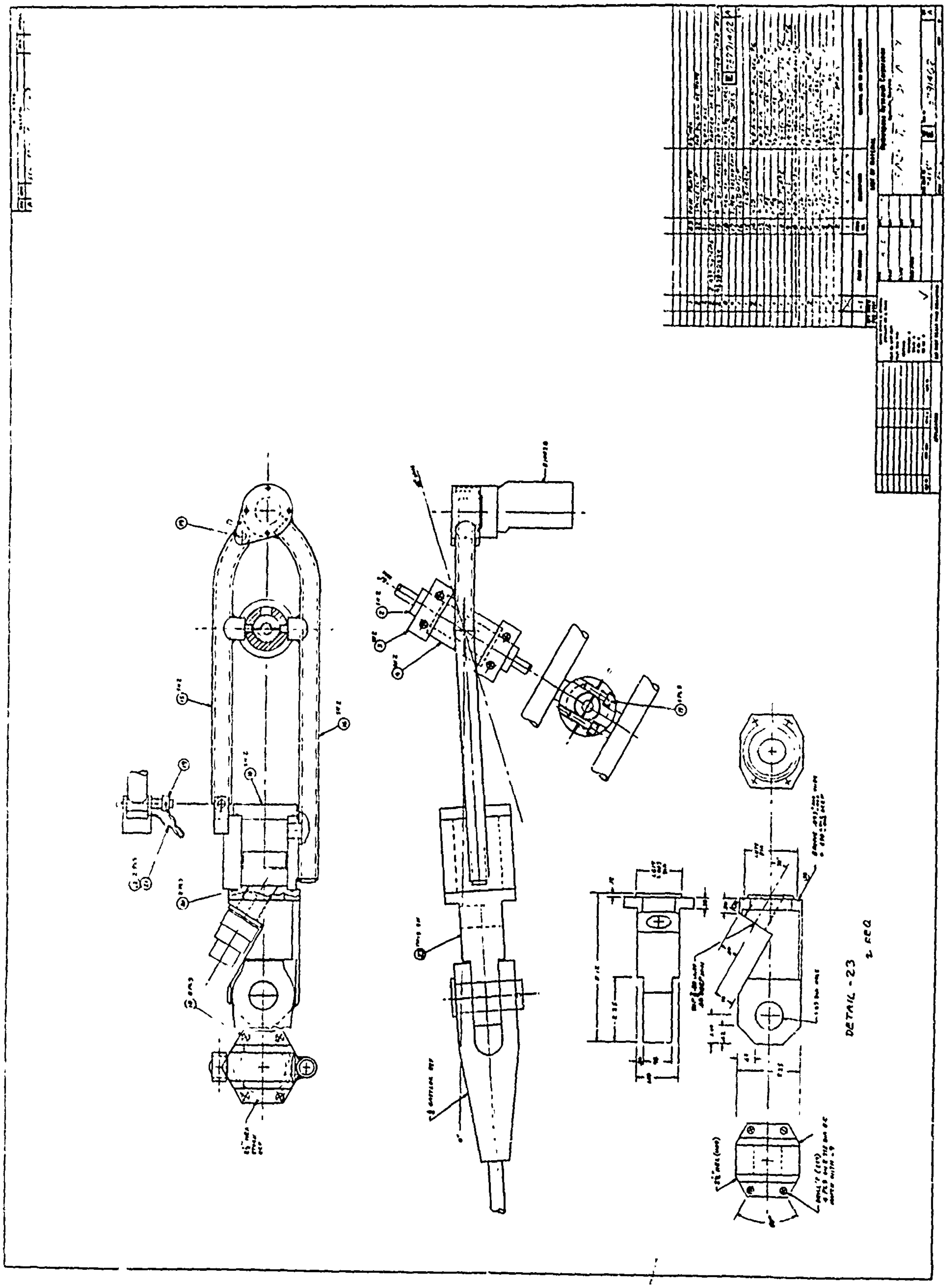
DETAIL-20
DETAIL-22
DETAIL-23
DETAIL-19
DETAIL-18
N B DEPRESSOR DETAILS
78791401



DETAIL-2
DETAIL-3
DETAIL-5
DETAIL-6
DETAIL-7
DETAIL-8 RH
-9 LH
DETAIL-10
DETAIL-56
DETAIL-60
DEPRESSOR DETAILS


N.B. DEPRESSOR MODS
DETAIL-7 & -8
-1 BODY MOD
-3 BLOCK
-2 CLOSURE
-5 & -6 BAR
A-A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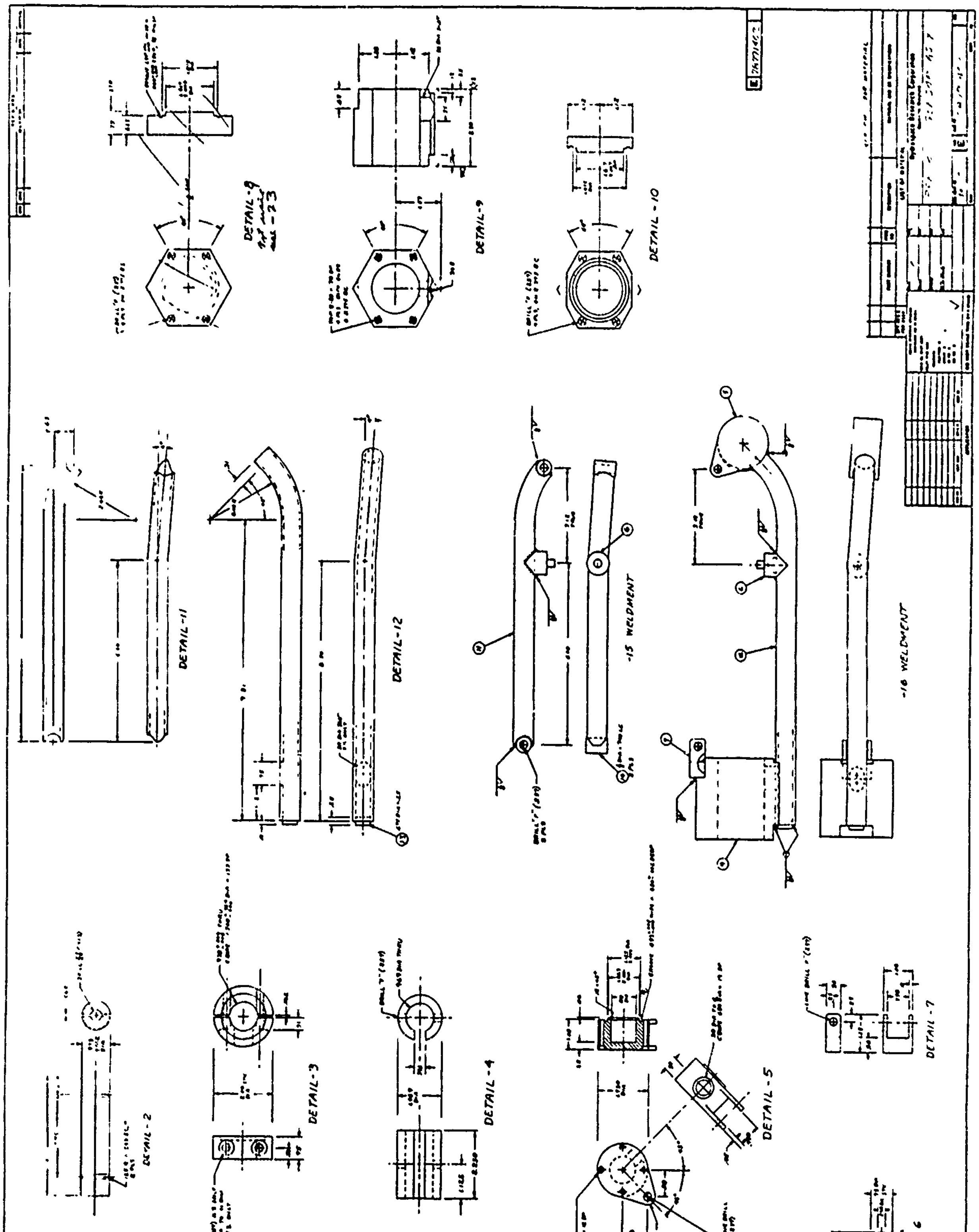
DETAIL-2
DETAIL-3
DETAIL-4
DETAIL-5
DETAIL-6
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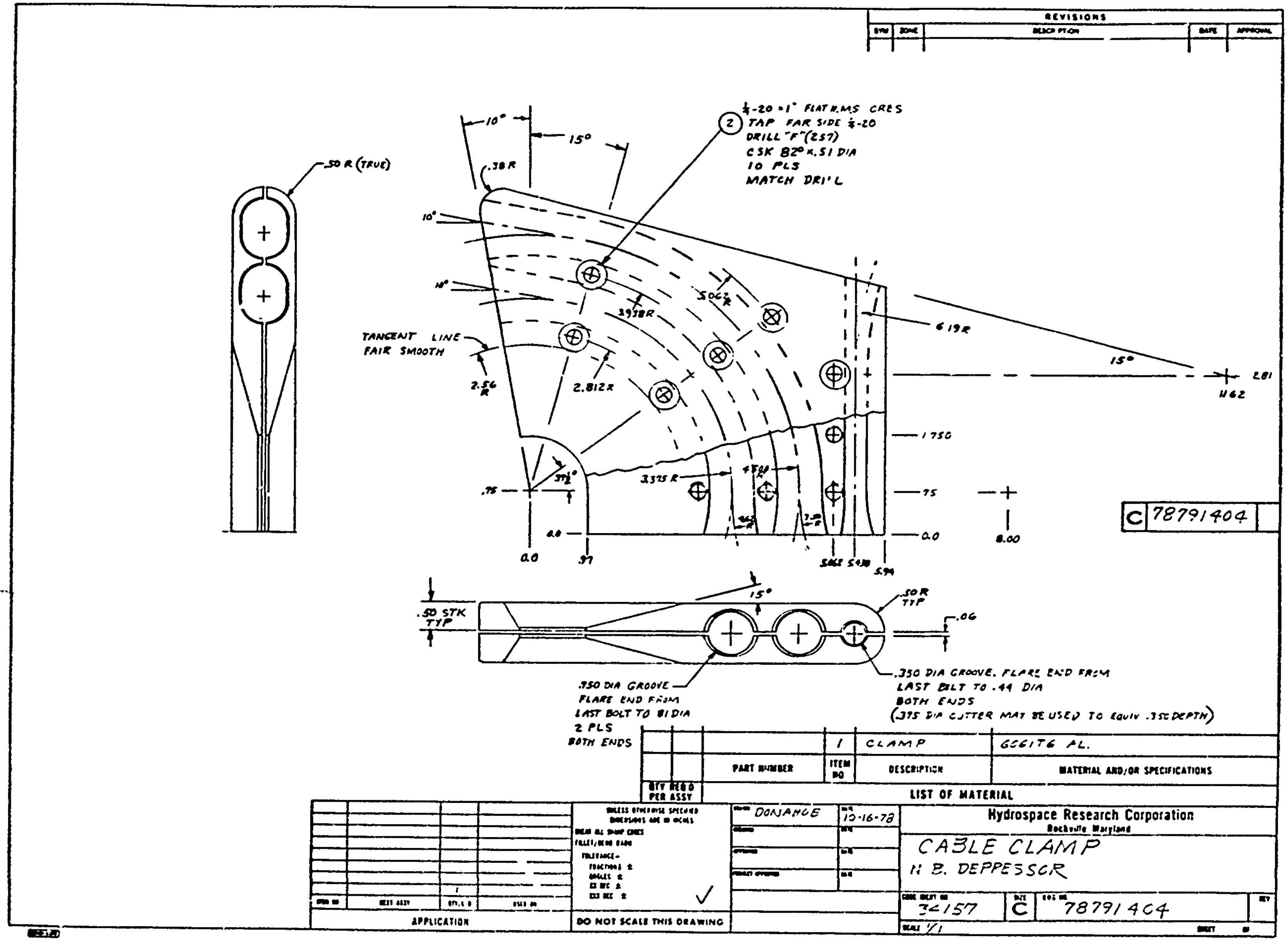
DETAIL-9
DETAIL-10
DETAIL-11
DETAIL-12
-15 WELDMENT
-16 WELDMENT


REVISIONS
SYM
ZONE
DESCRIPTION
DATE
APPROVAL
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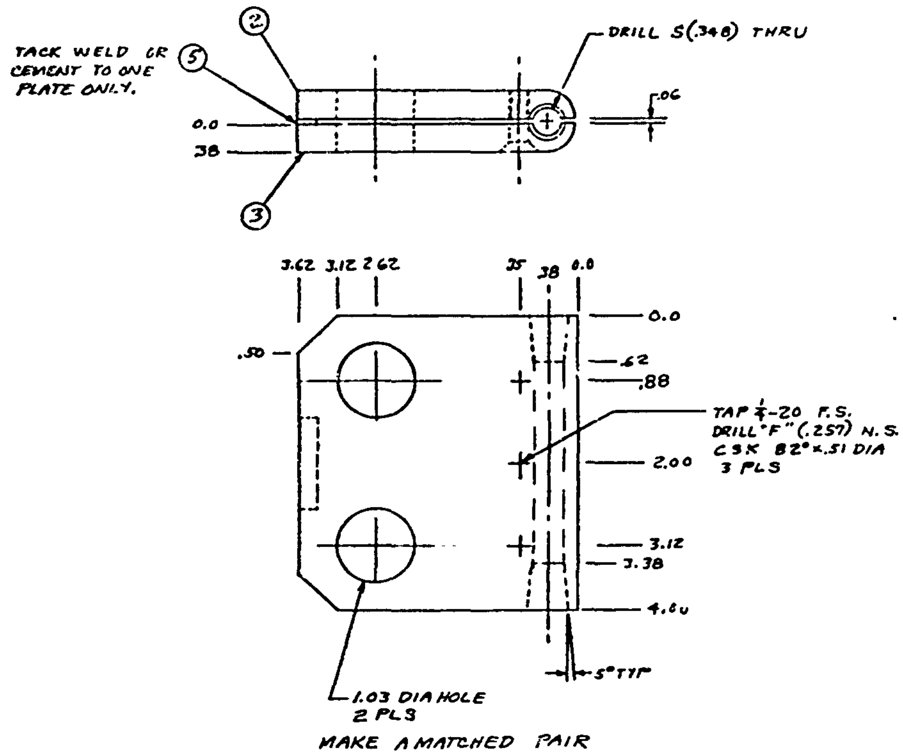
TAP FAR SIDE 1/4-20
DRILL "F" (257)
CSK 82° x .51 DIA
10 PLS
MATCH DRI'L
.50 R (TRUE)
TANGENT LINE
FAIR SMOOTH
.38 R
3.938R
5.062 R
6.19R
2.812R
2.56 R
3.375 R
15°
10°
2.81
11.62
1.750
.75
0.0
8.00
0.0
.97
5.94
C 78791404
.50 STK TYP
.50 R TYP
.06
.350 DIA GROOVE. FLARE END FROM
LAST BOLT TO .44 DIA
BOTH ENDS
(.375 DIA CUTTER MAY BE USED TO EQUIV .350 DEPTH)
.350 DIA GROOVE
FLARE END FROM
LAST BOLT TO .81 DIA
2 PLS
BOTH ENDS
1
CLAMP
6061T6 AL.
QTY REQD PER ASSY
PART NUMBER
ITEM NO
DESCRIPTION
MATERIAL AND/OR SPECIFICATIONS
LIST OF MATERIAL
APPLICATION
DO NOT SCALE THIS DRAWING
DONAHOE
10-16-78
Hydrospace Research Corporation
Rockville Maryland
CABLE CLAMP
H. B. DEPRESSOR
34157
C
78791404
SCALE 1/1

REVISIONS				
SYM	ZONE	DESCRIPTION	DATE	APPROVAL



C 78791406

QTY REQ'D PER ASSY	PART NUMBER	ITEM NO	DESCRIPTION	MATERIAL AND/OR SPECIFICATIONS
1		5	SPACER	.062 × ¼ × 1½ ALUM 6061T6
3		4	SCREW	¼-20 × ¾ CRES FLAT HD
1		3	PLATE	⅜ × 3⅝ × 2 ALUM 6061T6
1		2	PLATE	⅜ × 3⅝ × 4 ALUM 6061T6
X		1	CLAMP ASSY	
1				

LIST OF MATERIAL

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
BREAK ALL SHARP EDGES
FILLET/BEND RADII
TOLERANCE–
FRACTIONS ±
ANGLES ±
XX DEC ±
XXX DEC ±

DO NOT SCALE THIS DRAWING

APPLICATION: NEXT ASSY 1 — QTY/A 1

DRAWN DONAHOE — DATE 8-21-79

Hydrospace Research Corporation
Rockville, Maryland

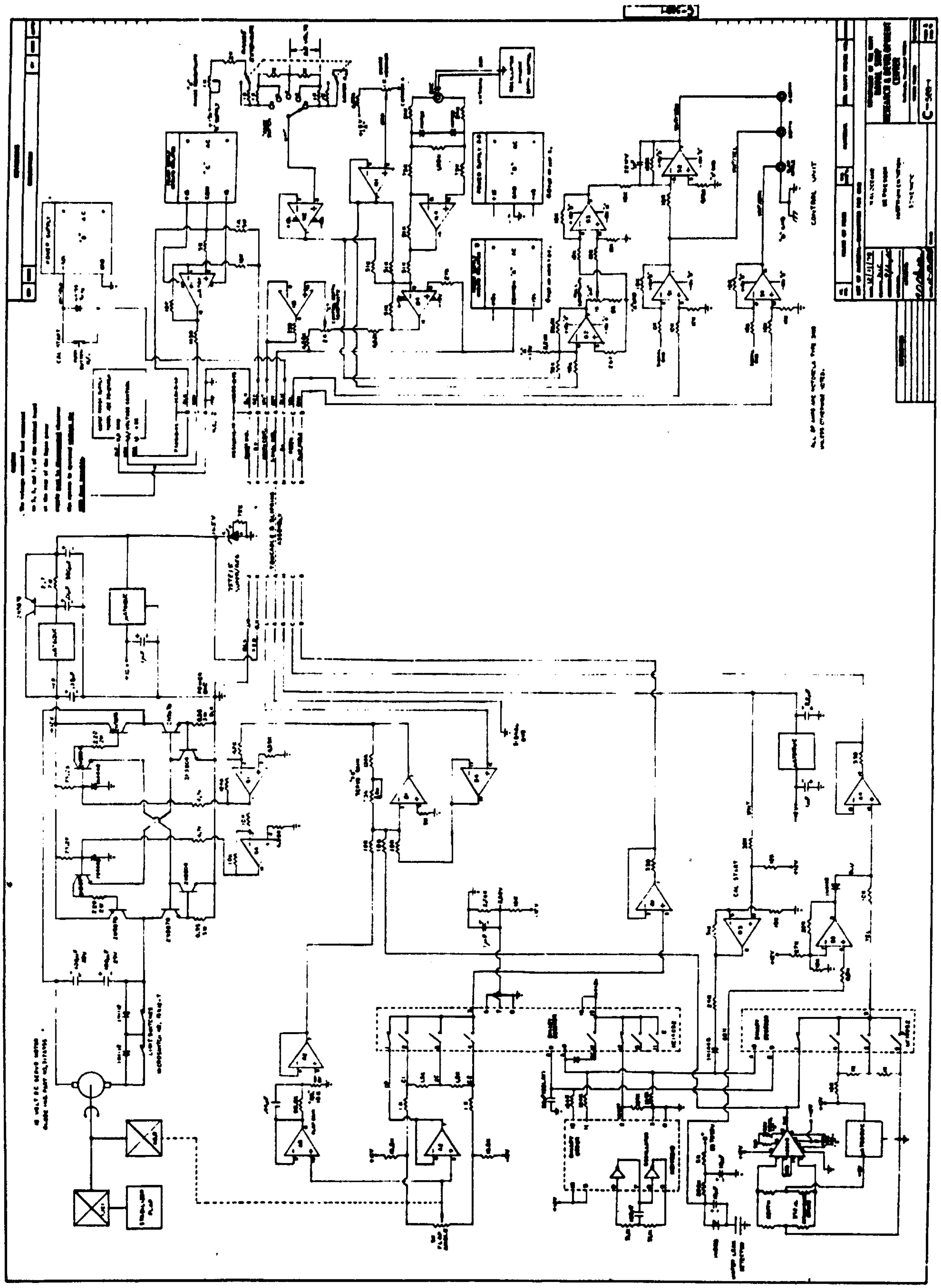
CLAMP
SENSOR TO TOW CABLE

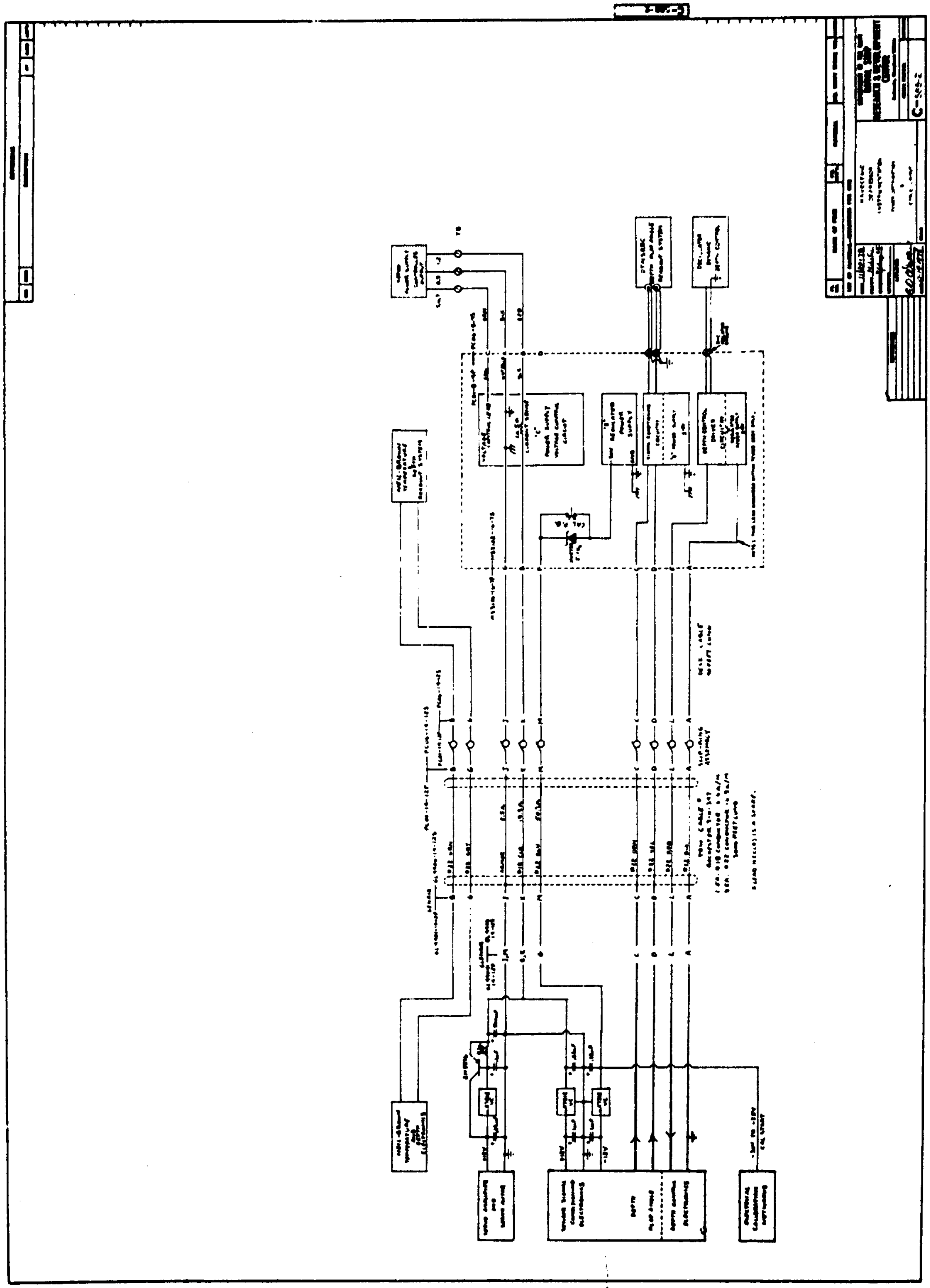
CODE IDENT NO 34157 — SIZE C — DWG NO 78791406

SCALE FULL — SHEET

APPENDIX D

CONTROL SYSTEM CIRCUITRY AND CABLING DIAGRAMS





REFERENCES

1. Cuthill, E., "FORTRAN IV Program for the Calculation of the Equilibrium Configuration of a Flexable Cable in a Uniform Stream," NSRDC Report 2531 (Feb 1968)

2. Folb, R., "Experimental Determination of Hydrodynamic Loading for Ten Cable Fairing Models," DTNSRDC Report 4610 (Nov 1975).

3. Pode, L., "Table for Computing the Equilibrium Configuration of a Flexible Cable in a Uniform Stream," DTMB Report 687 (Mar 1951).

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